Operator's Manual
The Coherent
Mira Optima 900-F Laser

COHERENT
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Santa Clara, CA 95054

Technical Support

In the US:

Should you experience any difficulties with your laser or need any technical information, please visit our web site **www.Coherent.com**. Additional support can be obtained by contacting our Technical Support Hotline at 800-367-7890 (408-764-4557 outside the U.S.) or E-mail (clg.tech.services@Coherent.com). Telephone coverage is available Monday through Friday (except U.S. holidays and company shutdowns).

If you call outside our office hours, your call will be taken by our answering system and will be returned when the office reopens.

If there are technical difficulties with your laser that cannot be resolved by support mechanisms outlined above, please E-mail or telephone Coherent Technical Support with a description of the problem and the corrective steps attempted. When communicating with our Technical Support Department, via the web or telephone, the model and Laser Head serial number of your laser system will be required by the Support Engineer responding to your request.

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Coherent provides telephone and web technical assistance as a service to its customers and assumes no liability thereby for any injury or damage that may occur contemporaneous with such services. These support services do not affect, under any circumstances, the terms of any warranty agreement between Coherent and the buyer. Operation of any Coherent laser with any of its interlocks defeated is always at the operator's own risk.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Preface

This manual contains user information for the Mira Optima 900-F series mode-locked titanium:sapphire laser when pumped with the Coherent Verdi Series DPSS lasers (V5, V6, V8, and V10) or Coherent Ion Lasers. Refer to Appendix A, Ion Laser Pumping for Coherent pump laser information. This manual does not support other pump lasers.

Read this manual carefully before operating the laser for the first time. Special attention should be given to the material in Chapter One, Laser Safety, that describes the safety features built into the Laser.

Use of controls or adjustments or performance of procedures other than those specified in this manual may result in hazardous radiation exposure.

U.S. Export Control Laws Compliance

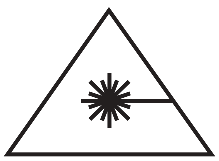
It is the policy of Coherent to comply strictly with U.S. export control laws.

Export and re-export of lasers manufactured by Coherent are subject to U.S. Export Administration Regulations, that are administered by the Commerce Department. In addition, shipments of certain components are regulated by the State Department under the International Traffic in Arms Regulations.

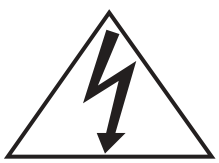
The applicable restrictions vary depending on the specific product involved and its destination. In some cases, U.S. law requires that U.S. Government approval be obtained prior to resale, export or re-export of certain articles. When there is uncertainty about the obligations imposed by U.S. law, clarification should be obtained from Coherent or an appropriate U.S. Government agency.

Symbols Used in This Manual and on the Laser System

This symbol is intended to alert the operator to the presence of important operating and maintenance instructions.



This symbol is intended to alert the operator to the danger of exposure to hazardous visible and invisible laser radiation.

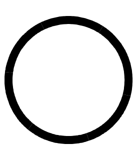


This symbol is intended to alert the operator to the presence of dangerous voltages within the product enclosure that may be of sufficient magnitude to constitute a risk of electric shock.

~

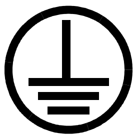
ALTERNATING CURRENT.

DIRECT CURRENT.

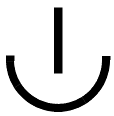


OFF OR STOP.

ON OR START.



PROTECTIVE CONDUCTOR TERMINAL.



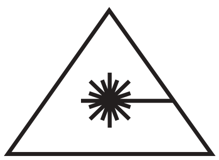
STANDBY.

OPERATOR'S MANUAL

CHAPTER ONE
LASER SAFETY

Optical Safety

Laser light, because of its special properties, poses safety hazards not associated with light from conventional sources. The safe use of lasers requires that all laser users, and everyone near the laser system, are aware of the dangers involved. The safe use of the laser depends upon the user being familiar with the instrument and the properties of intense beams of coherent light.

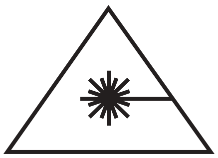


Direct eye contact with the output beam from the laser will cause serious damage and possible blindness.

The greatest concern when using a laser is eye safety. In addition to the main beam, there are often many smaller beams present at various angles near the laser system. These beams are formed by specular reflections of the main beam at polished surfaces such as lenses or beamsplitters. While weaker than the main beam, such beams may still be sufficiently intense to cause eye damage.

Laser beams are powerful enough to burn skin, clothing or paint. They can ignite volatile substances such as alcohol, gasoline, ether and other solvents, and can damage light-sensitive elements in video cameras, photomultipliers and photodiodes. The laser beam can ignite substances in its path, even at some distance. The beam may also cause damage if contacted indirectly from reflective surfaces. For these reasons, and others, the user is advised to follow the precautions below.

1. Observe all safety precautions in the pre-installation and operator’s manual.
2. Extreme caution should be exercised when using solvents in the area of the laser.
3. Limit access to the laser to qualified users who are familiar with laser safety practices and who are aware of the dangers involved.
4. Never look directly into the laser light source or at scattered laser light from any reflective surface. Never sight down the beam into the source.
5. Maintain experimental setups at low heights to prevent inadvertent beam-eye encounter at eye level.



Laser safety glasses can present a hazard as well as a benefit; while they protect the eye from potentially damaging exposure, they block light at the laser wavelengths, that prevents the operator from seeing the beam. Therefore, use extreme caution even when using safety glasses.

6. As a precaution against accidental exposure to the output beam or its reflection, those using the system should wear laser safety glasses as required by the wavelength being generated.
7. Avoid direct exposure to the laser light. The intensity of the beam can easily cause flesh burns or ignite clothing.
8. Use the laser in an enclosed room. Laser light will remain collimated over long distances and therefore presents a potential hazard if not confined.
9. Post warning signs in the area of the laser beam to alert those present.
10. Advise all those using the laser of these precautions. It is good practice to operate the laser in a room with controlled and restricted access.

Electrical Safety

The Mira Optima uses AC and DC voltages in the laser head and controller. All units are designed to be operated with protective covers in place. Certain procedures in this manual require removal of the protective covers. These procedures are normally used by a qualified trained service personnel. Safety information contained in the procedures must be strictly observed by anyone using the procedures.

Pump Source

Observe all safety precautions associated with the pump laser. Refer to the pump laser operator's manual for additional safety precautions.

Safety Features and Compliance to Government Requirements

The following features are incorporated into the instrument to conform to several government requirements. The applicable United States Government requirements are contained in 21 CFR, subchapter J, part II administered by the Center for Devices and Radiological Health (CDRH). The European Community requirements for product safety are specified in the Low Voltage Directive

(LVD) (published in 73/23/EEC and amended in 93/68/EEC). The Low Voltage Directive requires that lasers comply with the standard EN 61010-1 “Safety Requirements For Electrical Equipment For Measurement, Control and Laboratory Use” and EN60825-1 “Radiation Safety of Laser Products”. Compliance of this laser with the (LVD) requirements is certified by the CE mark.

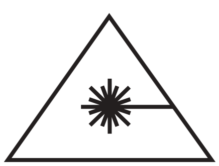
The Mira Optima laser does not include an integral power source; it utilizes the output beam of a pump laser to produce coherent light.

Laser Classification

The governmental standards and requirements specify that the laser must be classified according to the output power or energy and the laser wavelength. The Mira Optima is classified as Class IV based on 21 CFR, subchapter J, part II, section 1040-10 (d). According to the European Community standards, the Mira Optima is classified as Class 4 based on EN 60825-1, clause 9. In this operator’s manual and other documentation of the Mira Optima, the classification will be referred to as Class 4.

Protective Housing

The laser head is enclosed in a protective housing that prevents human access to radiation in excess of the limits of Class I radiation as specified in the Federal Register, July 31, 1975, Part II, Section 1040.10 (f) (1) and Table 1-A/EN 60825-1, clause 4.2 except for the output beam, which is Class IV.



Use of controls or adjustments or performance of procedures other than those specified in the manual may result in hazardous radiation exposure.

Use of the system in a manner other than that described herein may impair the protection provided by the system.

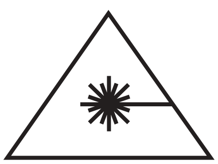
Location of Safety Labels

Refer to Figure 1-1 for a description and location of all safety labels. These include warning labels indicating removable or displaceable protective housings, apertures through which laser radiation is emitted and labels of certification and identification [CFR 1040.10(g), CFR 1040.2, and CFR 1010.3/EN60825-1, Clause 5].

- When the pumping beam is allowed to impinge on the titanium:sapphire crystal, both laser and collateral radiation are produced. The laser beam is emitted from the laser aperture that is clearly labeled:

AVOID EXPOSURE
VISIBLE AND INVISIBLE LASER RADIATION IS EMITTED FROM THIS APERTURE.

- The laser is designed to be used with the covers in position and this cover shields the operator from all collateral radiation. During initial alignment and maintenance operations, such as mirror alignment, it will be necessary to remove the covers. The covers are not interlocked with the circuitry of the pumping laser but a label provides a warning about exposure to the radiation.



Operation of laser with covers removed will allow access to hazardous visible and invisible radiation. The laser housings should only be opened for the purposes of maintenance and service by trained personnel cognizant of the hazards involved. Extreme caution must be observed in operating the laser with the cover removed. There are high-power reflections that may exit at unpredictable angles from the laser head. These beams have sufficient energy density to cause permanent eye damage or blindness.

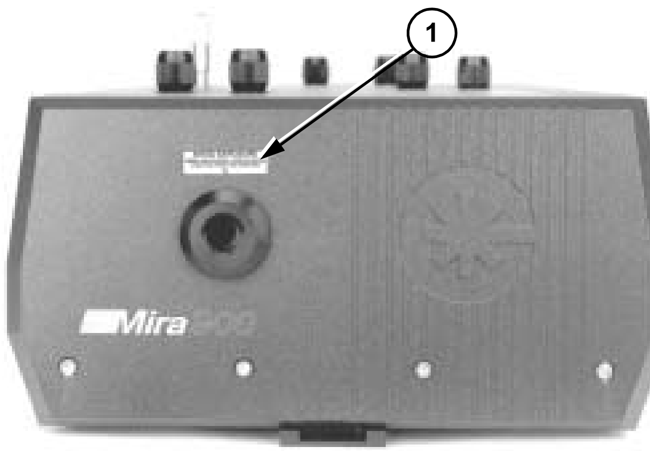
Electromagnetic Compatibility

The European requirements for Electromagnetic Compliance (EMC) are specified in the EMC Directive (published in 89/336/EEC).

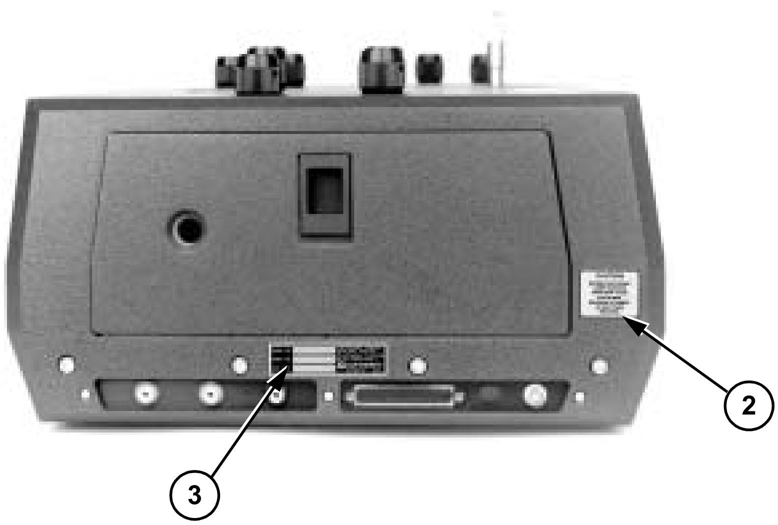
Conformance (EMC) is achieved through compliance with the harmonized standards EN55011 (1991) for emission and ENC50082-1 (1992) for immunity.

The laser meets the emission requirements for Class A, group 1 as specified in EN55011 (1991).

Compliance of this laser with the (EMC) requirements is certified by the CE mark.



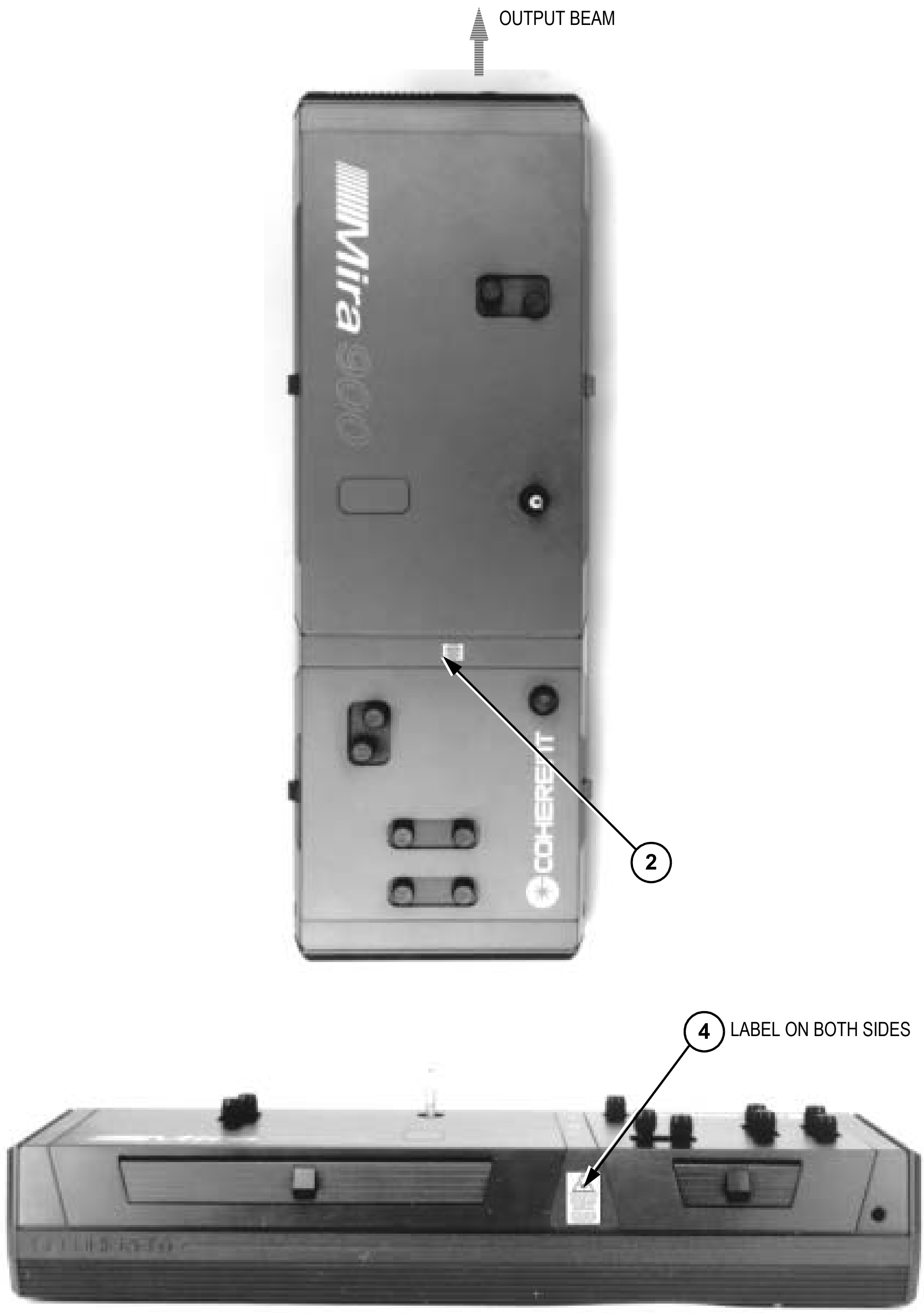
FRONT BEZEL



REAR BEZEL

Note: Key is located on sheet 3 of 3

Figure 1-1. Safety Features and Labels (Sheet 1 of 3)



Note: Key is located on sheet 3 of 3

Figure 1-1. Safety Features and Labels (Sheet 2 of 3)

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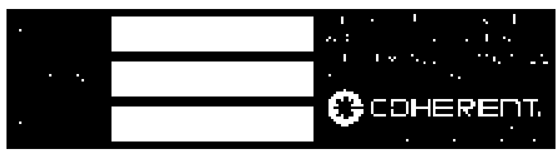
2.



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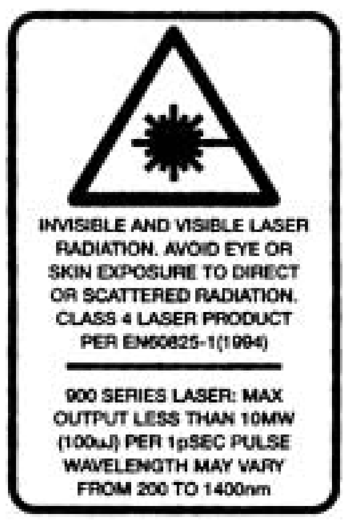


4.

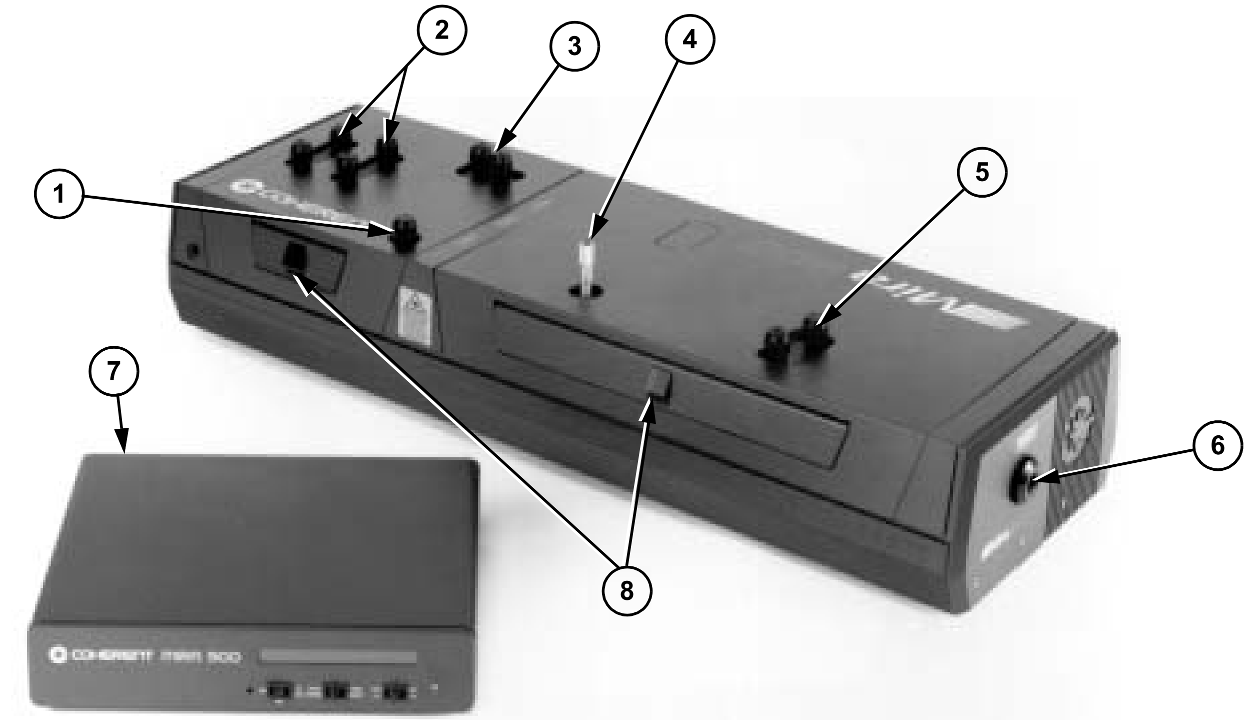
Figure 1-1. Safety Features and Labels (Sheet 3 of 3)

OPERATOR'S MANUAL

CHAPTER TWO
DESCRIPTION AND SPECIFICATIONS

System Description

The Mira Optima 900-F is a mode-locked ultrafast laser that uses titanium:sapphire (sapphire doped with titanium) as the gain medium and is tunable from 700 nm to 980 nm. It consists of the laser head and Optima controller. The recommended pump lasers for the Mira Optima 900-F are the Coherent Verdi Series DPSS lasers (V5, V6, V8, and V10) and the Coherent Innova Series Ion lasers (200, 300, 400, and Sabre). The Mira Optima laser head is shown in Figure 2-1.



1. BP2 translation adjust
2. Pump optics controls
3. End mirror (M7) controls
4. Tuning (BRF) controls
5. Aperture (slit) controls
6. Output beam aperture
7. Controller
8. Cover latches

Figure 2-1. Mira Optima 900-F Laser

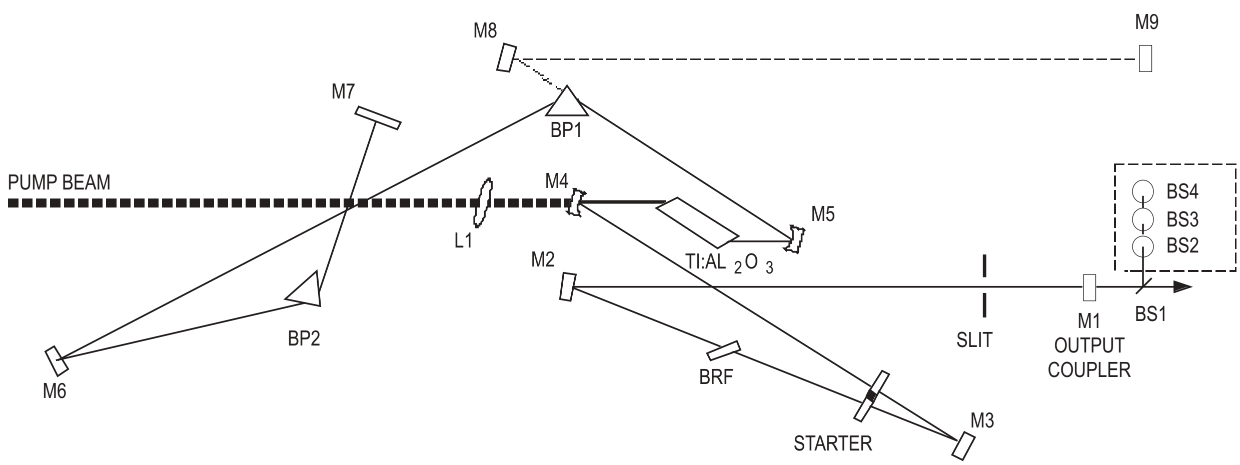
The technique used to mode-lock the Mira Optima laser is referred to as Kerr Lens Mode-locking (KLM). The optical cavity is specifically designed to utilize changes in the spatial profile of the beam, i.e. self-focusing due to the optical Kerr effect, produced in the titanium:sapphire crystal. Occurring in the gain medium itself, this mechanism results in higher round trip gain in the mode-locked (high peak power) versus continuous wave (CW) (low peak power) operation due to an increased overlap between the pumped gain profile and the circulating cavity mode. In addition, an aperture is

placed at a position within the cavity at a location where the mode-locked beam diameter is smaller to produce lower round trip loss in mode-locked versus CW operation. Group velocity dispersion (GVD) compensation is accomplished with a pair of intracavity prisms and produces near transform-limited pulses of less then 150 femtoseconds.

Features included in the system to aid alignment and optimization include:

- An auxiliary cavity that produces an alignment beam
- Built-in alignment apertures
- An internal power meter
- An internal fast photodiode
- A CW-component detector (external scanning etalon)
- A mode-locking starter (galvo mounted Brewster plates)

For alignment purposes, BP1 is removed from the beam path to create an auxiliary cavity. The auxiliary cavity excludes BP1, BP2, M6, and M7 from the optical path (refer to Figure 2-2). The auxiliary cavity is used during the initial alignment of the laser cavity. For mode-locked operation, BP1 re-directs the beam into the main cavity and M8 and M9 are excluded from the optical path.



BP:	Brewster prism	L:	Focusing lens
BRF:	Birefringent filter	M:	Mirror
BS:	Beamsplitter	$TiAl_2O_3$:	Titanium:sapphire crystal

Figure 2-2. Optical Schematic

An optical schematic of the Mira 900-F is shown in Figure 2-2. The laser head contains several photodiodes that provide:

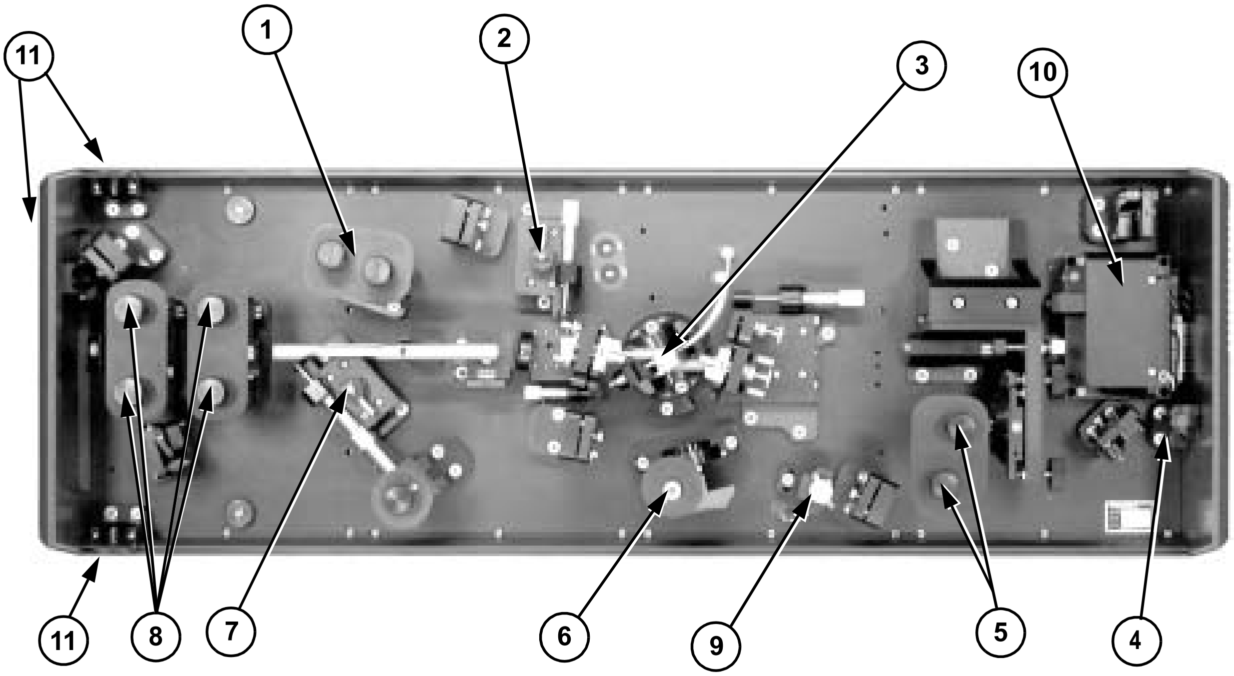
- Fluorescence or power level signals
- An output to monitor the pulse-train
- The signal for a sensitive CW detection scheme

The Optima control box performs the following functions:

- Displays the relative fluorescence or power level signals
- Provides drive voltages to operate the intracavity starter and the CW detection scheme etalon galvos. If any CW component is detected, the control box can turn the starter on automatically to establish mode-locked operation.

The access hatches use a latching mechanism in place of screws. This allows easy access to the laser cavity and creates an air-tight seal. The controls that are frequently used during daily operation are accessible through the covers. The function of all Mira Optima controls are described in Chapter Three, Controls and Indicators. Major laser head components are illustrated in Figure 2-3.

Specifications and typical power tuning curves for Verdi-pumped Mira 900-F systems with XW optics are listed in Table 2-1 and Table 2-2 respectively. Refer to Appendix A for information on argon ion-pumped systems.



1. M7 (end mirror) controls
2. BP1 Brewster prism
3. Titanium:sapphire crystal assembly
4. Output beam window
5. Slit (width and horizontal position) controls
6. BRF control micrometer
7. BP2 Brewster prism
8. Pump mirror controls
9. Mode-locking starter mechanism
10. Optima system detectors
11. Pump beam input windows

Figure 2-3. Major Laser Head Components for the Mira Optima 900-F

Table 2-1. Mira Optima 900-F Laser Specifications (XW Optics)

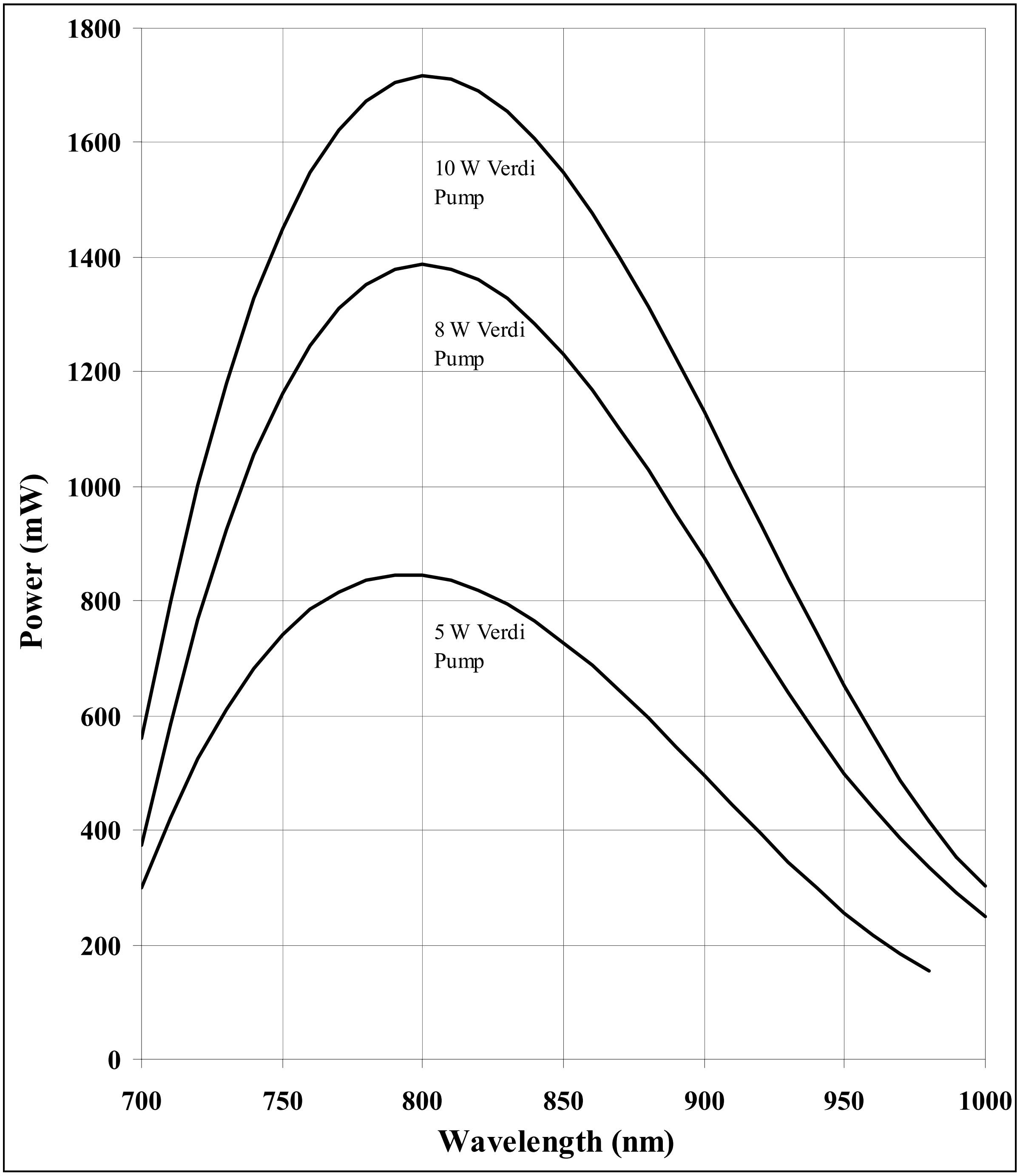
Pump laser [1]	Verdi V5	Verdi V8	Verdi V10
Pump power	5 Watts	8 Watts	10 Watts
Tuning Range[2]	700 to 980 nm	700 to 980 nm	700 to980 nm
Average Power[3]	650 mW	1000 mW	1300 mW
Autocorrelation [4]	200 fs	200 fs	200 fs
Repetition rate	76 MHz	76 MHz	76 MHz
Peak power [3] [4]	65 kW	100 kW	130 kW
Noise [5]	< 0.1%	< 0.1%	< 0.1%
Beam diamete [6]r	0.8 ± 0.1 mm	0.8 ± 0.1 mm	0.8 ± 0.1 mm
Divergence [7]	1.7 ± 0.2 mrad	1.7 ± 0.2 mrad	1.7 ± 0.2 mrad
Spatial mode [8]	TEM_{00}	TEM_{00}	TEM_{00}
Polarization	Horizontal	Horizontal	Horizontal

All specifications are subject to change without notice.

1. Specifications only apply with the recommended pump lasers at the power levels indicated
2. System is shipped and installed with only one optics set specified at the time of purchase
3. At the peak of the optics set
4. Multiply by 0.65 $sech^2$ deconvolution factor for pulse duration
5. RMS measured in a 10 Hz to 2 MHz bandwidth
6. Measured at the Output Coupler
7. Full angle divergence
8. Typical measured M^2 value of 1.1

Table 2-2. Mira Optima 900-F Typical[1] Tuning Curves[2] (XW Optics)

VERDI PUMPED MIRA OPTIMA 900-F (XW OPTICS)



1. Typical tuning data is supplied as a reference and is not specified. Refer to Table 2-1 for tuning range and power level specifications.
2. When operating the laser above 900 nm, the cavity must be purged with N_2 for optimal mode-locked performance.

OPERATOR'S MANUAL

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CHAPTER THREE
CONTROLS AND INDICATORS

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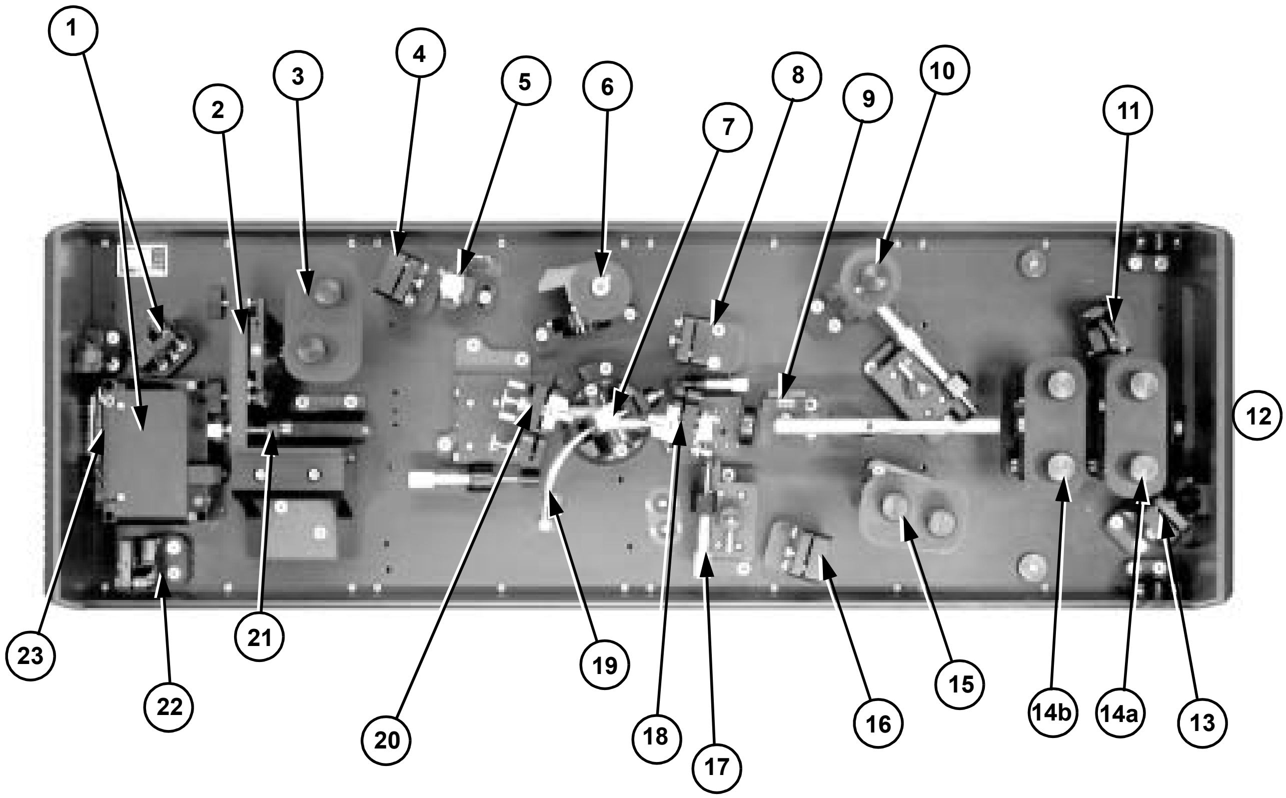
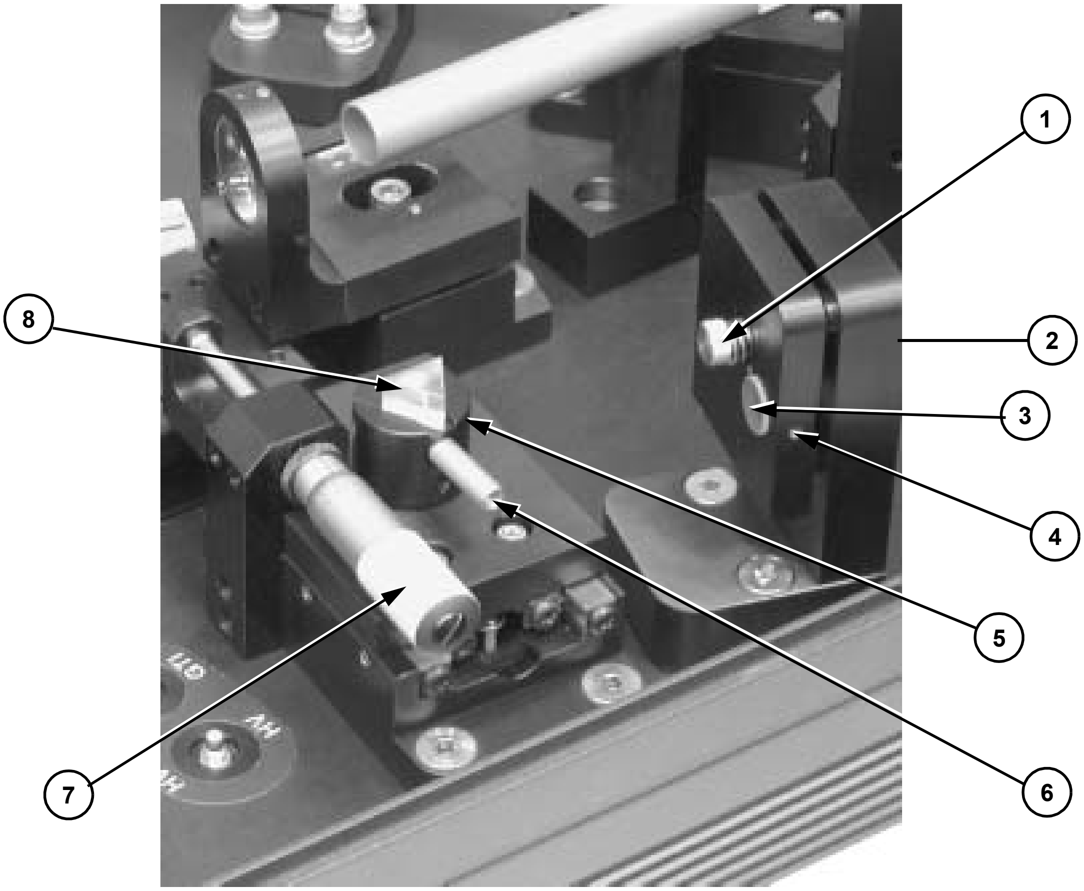


Figure 3-1. Mira Optima Controls and Indicator Locations

Table 3-1. Mira Optima Controls and Indicators Location

DESIGNATION	CALLOUT	DESCRIPTION	REFERENCE FIGURE
BP1	17	Brewster prism 1	3-2
BP2	10	Brewster prism 2	3-7
BRF	6	Birefringent Filter	3-8
BS1 - BS4	1	Beamsplitters 1 through 4	3-20
Crystal	7	Titanium:sapphire crystal	3-3
L1	9	Pump Lens	3-16
M1	2	Output coupler	3-4, 3-11
M2	8	Flat cavity mirror	3-9
M3	4	Flat cavity mirror	3-4, 3-18
M4	18	Curved mirror	3-3, 3-21
M5	20	Curved mirror	3-3, 3-5
M6	11	Flat mirror	3-15
M7	15	Flat end mirror	3-6
M8	16	Flat mirror (auxiliary cavity)	3-2, 3-17
M9	22	Auxiliary cavity end mirror	3-19
P0	13	Pump fold mirror	3-10
P1, P2	14a	Pump mirrors 1 and 2	3-10
P3, P4	14b	Pump mirrors 3 and 4	3-10
Slit	3	— —	3-4
Starter	5	— —	3-18
— —	Not shown	Controller	3-12, 3-13
— —	12	Laser head interface panel	3-14
— —	19	Cooling water lines	3-3
— —	21	Cavity length control	3-11
— —	23	Head board	3-11

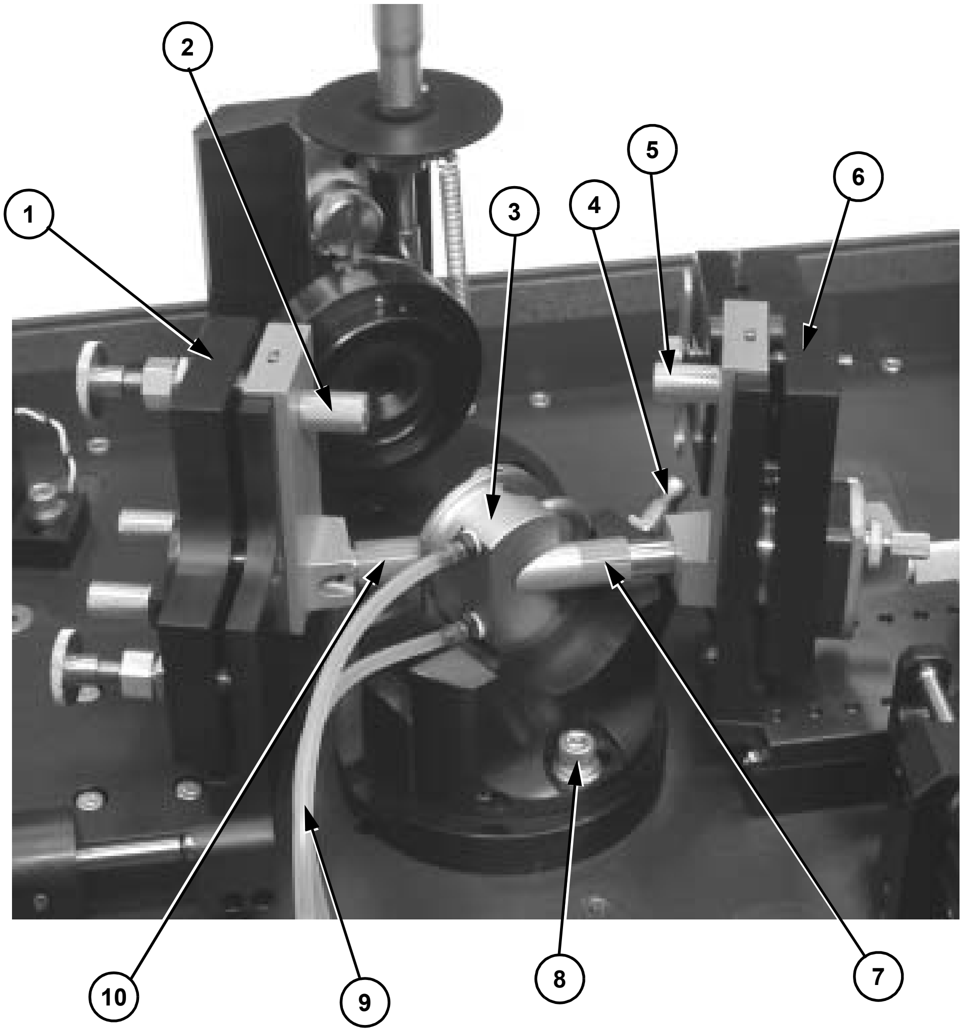


1. Tensioning screw for M8 horizontal and vertical tilt angle controls
2. M8 horizontal and vertical tilt angle control (not visible in figure, refer to Figure 3-17)
3. M8 optic
4. M8 optic setscrew
5. BP1 assembly setscrew (not visible in figure)
6. BP1 rotation adjust
7. BP1 micrometer translation adjust
8. Brewster prism 1 (BP1)

Figure 3-2. BP1 Brewster Prism/M8 Controls

Table 3-2. BP1 Brewster Prism/M8 Controls

CONTROL	FUNCTION
Tensioning screw for M8 horizontal and vertical tilt angle controls	Determines the amount of pressure required to adjust M8 vertical and horizontal tilt angle controls. This adjustment is performed at the factory and no further adjustments are necessary.
M8 horizontal and vertical tilt angle controls	Steers the beam to the M9 optic for the alignment of the auxiliary cavity.
M8 optic	Flat folding mirror located in the auxiliary cavity.
M8 optic setscrew	Secures M8 optic in the optic mount assembly.
BP1 assembly setscrew	This nylon-tipped setscrew provides tension when adjusting the prism assembly for Brewster's angle. The setscrew must be loosened when removing the BP1 assembly and re-tightened when installing the assembly. BP1 should not be routinely adjusted during operation or maintenance unless specifically directed by a procedure in this operator's manual.
BP1 rotation adjust	Allows rotational adjustment of BP1. The rotation adjustment sets the prism for Brewster's angle and sets the minimum deviation angle. This procedure should only be performed when replacing the prism assembly.
BP1 micrometer translation adjustment	Allows adjustment of BP1 into or out of the beam path. This adjustment determines the amount glass inserted into the beam path to compensate for group velocity dispersion (GVD). The more positive or the more negative GVD directions are determined by the reading on the micrometer. For more GVD, the number on the micrometer will increase. Procedures for initially positioning the prism are located in Chapter Five, Installation and Alignment.
Brewster prism 1 (BP1)	Part of the prism pair that provides GVD compensation in the laser cavity.



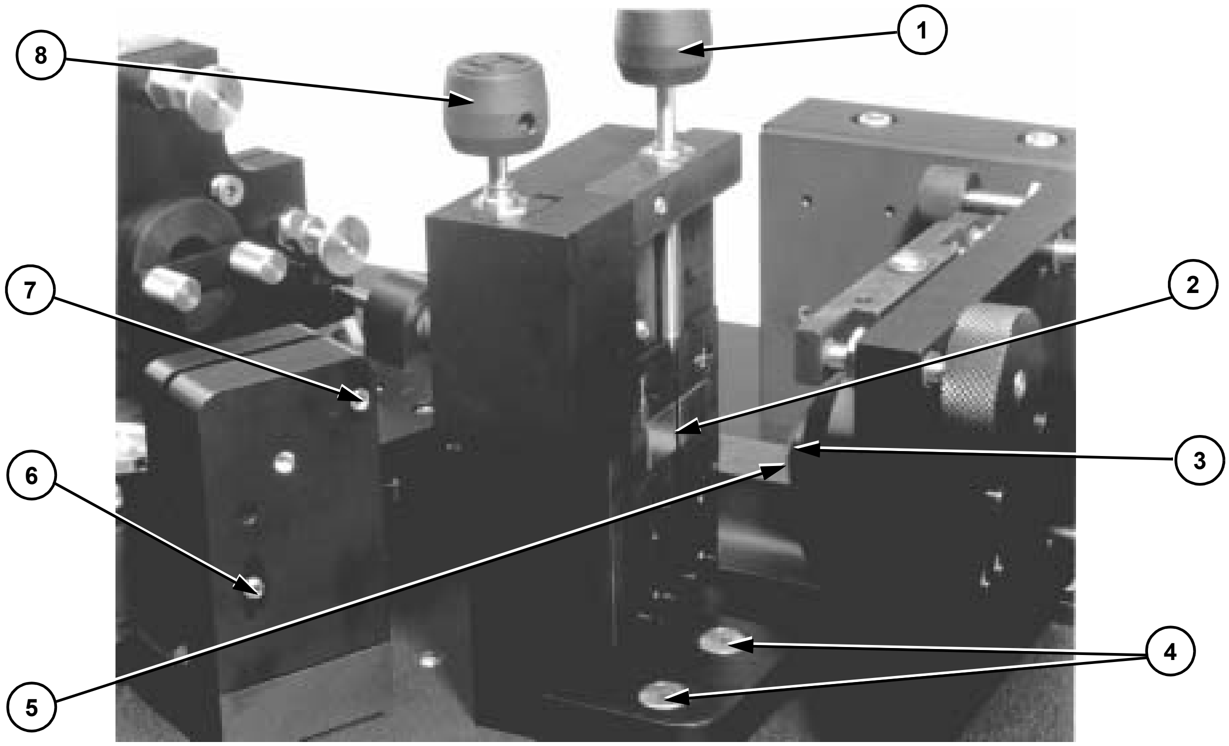
1. M5 optic mount assembly
2. Knurled thumbscrew
3. Titanium:sapphire crystal assembly
4. Titanium:sapphire crystal assembly face normal adjustment
5. Knurled thumbscrew
6. M4 optic mount assembly
7. Beam tube M4/crystal
8. Titanium:sapphire crystal translation set screw
9. Cooling water lines
10. Beam tube M5/crystal

Note: Refer to Figure 3-5 for additional M5 controls. Refer to Figure 3-21 for additional M4 controls.

Figure 3-3. Titanium:Sapphire Crystal Assembly/M4/M5 Controls

Table 3-3. Titanium:Sapphire Crystal Assembly/M4/M5 Controls

CONTROL	FUNCTION
M5 optic mount assembly	Mechanical assembly for the M5 pump-through optic. The translational position of this mount, as indicated by the micrometer reading, is set for optimal performance over the entire wavelength tuning range. This adjustment is performed at the factory and no further adjustments are necessary.
Knurled thumbscrew	Secures the M5/crystal beam tube to the M5 mount.
Titanium:sapphire crystal assembly	The titanium:sapphire crystal is the gain medium for the Mira Optima laser. The crystal assembly includes the crystal mount.
Titanium:sapphire crystal assembly face normal adjustment	Allows face normal C-axis adjustment of the titanium:sapphire crystal. This is a factory adjustment.
Knurled thumbscrew	Secures the M4/crystal beam tube to the M4 mount.
M4 optic mount assembly	Mechanical assembly for the M4 pump-through optic. The translational position of this mount, as indicated by the micrometer reading, is set for optimal performance over the entire wavelength tuning range. This adjustment is performed at the factory and no further adjustments are necessary.
Beam tube M4/crystal	Provides protection of crystal from dust. Confines stray reflections between crystal and M4. Note the position of the telescoping beam tube. Removal is unnecessary unless directed by a procedure in this operator’s manual.
Titanium:sapphire crystal translation set screw	Two Allen head screws allow the crystal to be centered with the pump beam. Normally, these screws are not adjusted during operation or maintenance. Incorrect adjustment could result in damage to the crystal. Perform this adjustment only when specifically directed by a procedure in this operator’s manual.
Cooling water lines	Provides cooling water flow to the crystal. Cooling water requirements and recommendations are discussed in Chapter Five, Installation and Alignment. The upper line is the water inlet.
Beam tube M5/crystal	Provides protection of crystal from dust. Confines stray reflections between crystal and M5. Note the position of the telescoping beam tube. Removal is unnecessary unless directed by a procedure in this operator’s manual.

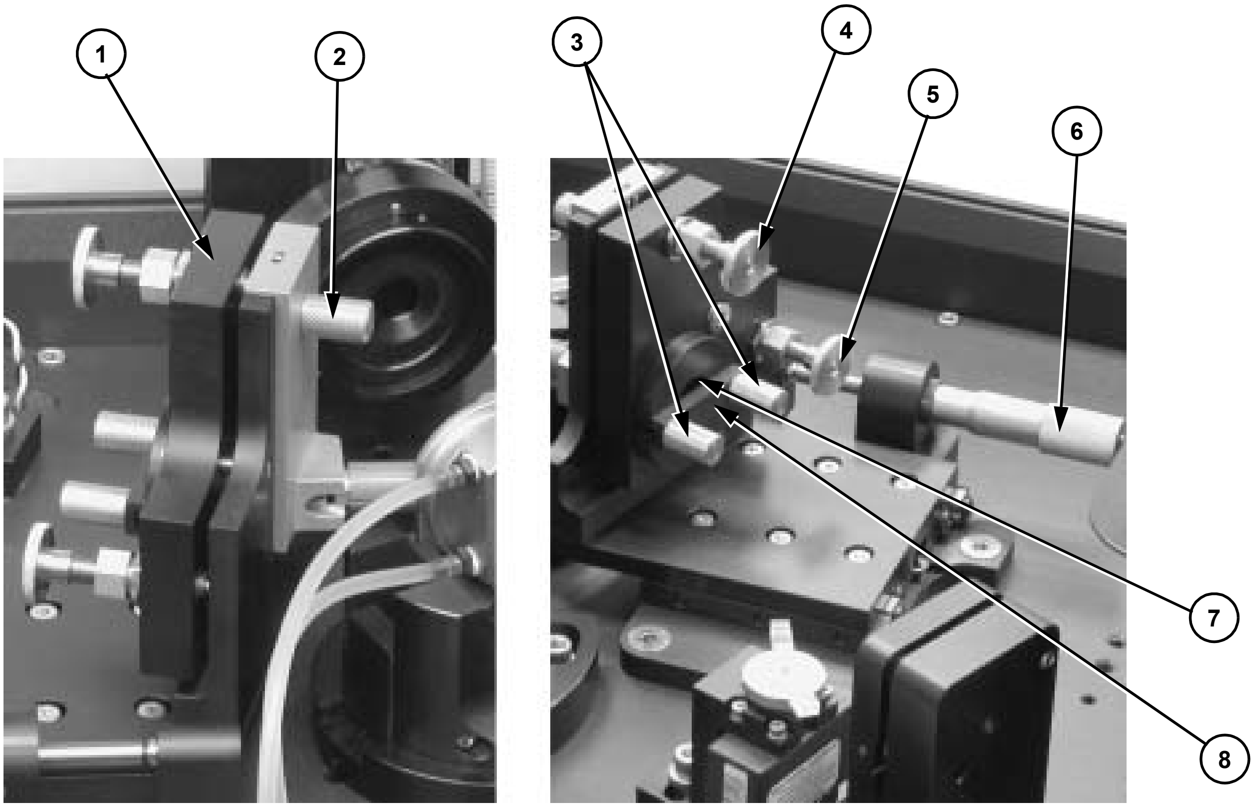


1. Slit width control
2. Slit
3. M1 optic setscrew
4. Slit assembly mounting screws
5. M1 optic (output coupler)
6. M3 vertical tilt angle control
7. M3 horizontal tilt angle control
8. Slit horizontal translation adjustment

Figure 3-4. Slit Assembly/M3 Controls

Table 3-4. Slit Assembly/M3 Controls

CONTROL	FUNCTION
Slit width control	Controls the width (horizontal opening) of the slit. Clockwise rotation opens the slit. Counterclockwise rotation closes the slit. The width of the slit is larger (opened) during initial alignment in continuous wave (CW) operation and is smaller during mode locked operation.
Slit	The slit produces a higher loss in the cavity for CW vs. mode-locked operation.
Slit assembly mounting screws	Secures the slit assembly to the baseplate.
M1 optic (output coupler)	Partially transmitting cavity end mirror that allows a portion of the output beam to exit the cavity.
M3 vertical tilt angle controls	Adjust the vertical tilt angle of M3 during alignment.
M3 horizontal tilt angle controls	Adjust the horizontal tilt angle of M3 during alignment.
Slit horizontal translation adjustment	Adjusts the horizontal translation of the slit to center the slit with respect to the beam.



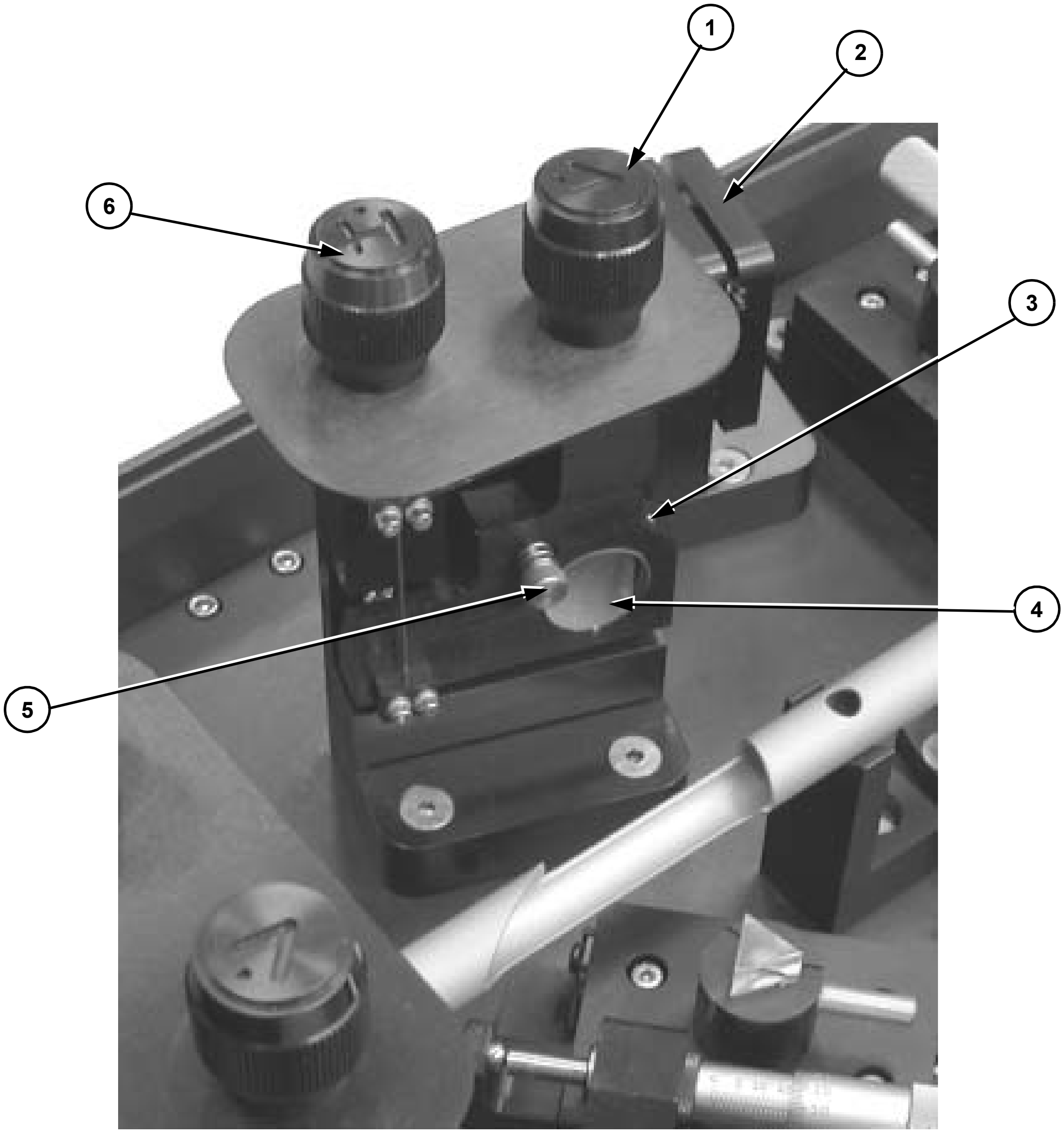
1. M5 optic mount assembly
2. Knurled thumbscrew
3. M5 assembly thumbscrews
4. M5 vertical tilt angle adjustment
5. M5 horizontal tilt angle adjustment
6. M5 micrometer adjustment
7. M5 optic (not visible in figure)
8. Beam block

Note: Refer to Figure 3-5 for additional M5 controls.

Figure 3-5. M5 Controls

Table 3-5. M5 Controls

CONTROL	FUNCTION
M5 optic mount assembly	Mechanical assembly for the M5 pump-through optic.
Knurled thumbscrew	Secures the M4/crystal beam tube to the M4 mount.
M5 assembly thumbscrews (2)	Secures the M5 optic assembly in the mount. Normally, M5 should only be removed for optic replacement. M5 can be cleaned in place.
M5 vertical tilt angle adjustment	Changes the vertical tilt angle of the fluorescent spot (or beam) during alignment. The results can be seen on M8 after BP1 has been translated out of the beam path.
M5 horizontal and vertical tilt angle adjustment	Changes the horizontal tilt angle of the fluorescent spot (or beam) during alignment. The results can be seen on M8 after BP1 has been translated out of the beam path.
M5 micrometer adjustment	Adjusts the distance (D2) between M5 and the titanium:sapphire crystal. This adjustment is normally verified during initial installation. The translational position is set for optimal performance over the entire wavelength tuning range. This adjustment is performed at the factory and no further adjustments are necessary.
M5 optic	Front surface mounted 10 cm radius optic in the main cavity.
Beam Block	Blocks the residual pump beam.

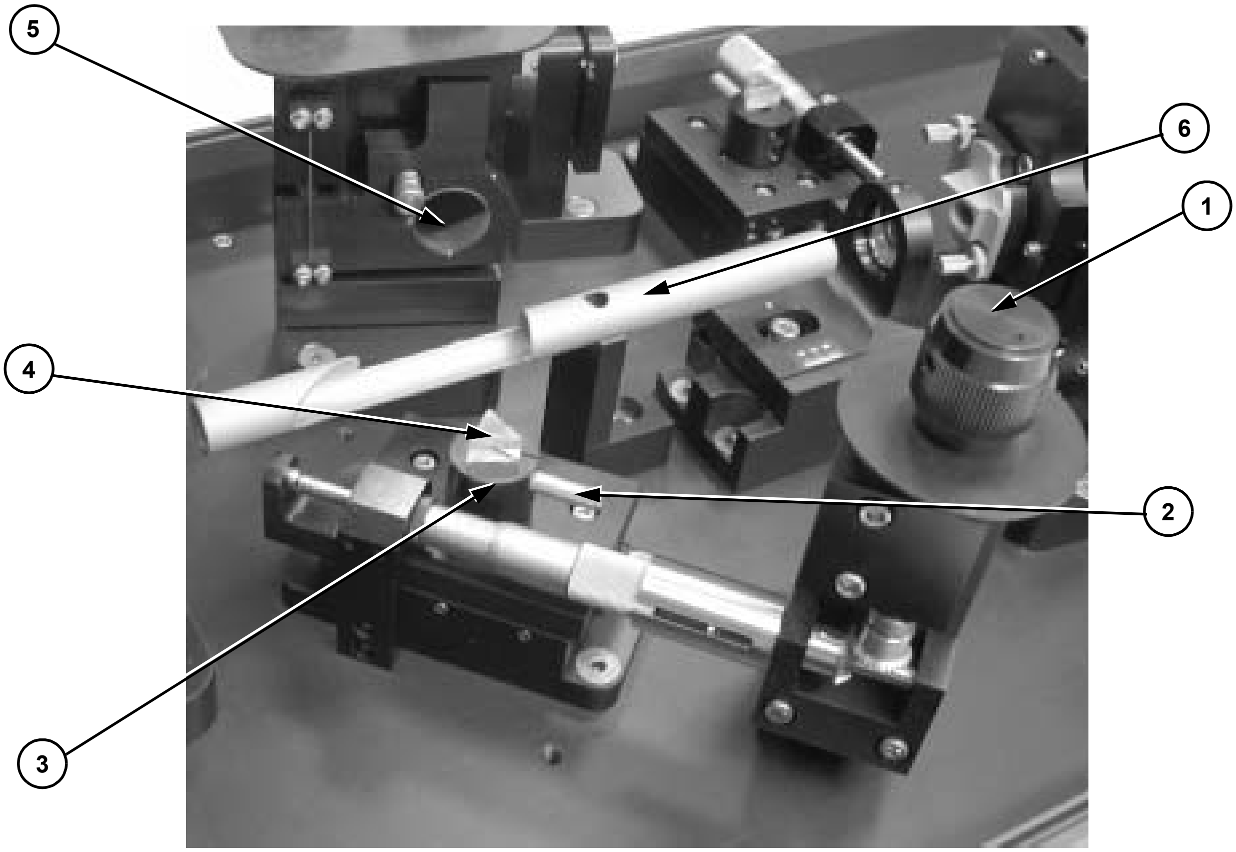


1. M7 vertical tilt angle adjustment
2. M8 assembly (refer to Figures 3-2 or 3-17)
3. M7 optic setscrew
4. M7 optic
5. M7 tensioning screw
6. M7 horizontal tilt angle adjustment

Figure 3-6. M7 Controls

Table 3-6. M7 Controls

CONTROL	FUNCTION
M7 vertical tilt angle adjustment	Changes the vertical tilt of the fluorescent spot (or beam) during operation and alignment.
M7 optic setscrew	Secures M7 optic in the optic mount assembly.
M7 optic	Flat-end mirror in the main cavity.
M7 tensioning screw	Determines the amount of pressure required to adjust M7 vertical and horizontal tilt angle controls. This adjustment is performed at the factory and no further adjustments are necessary.
M7 horizontal tilt angle adjustment	Changes the horizontal tilt of the fluorescent spot (or beam) during operation and alignment.

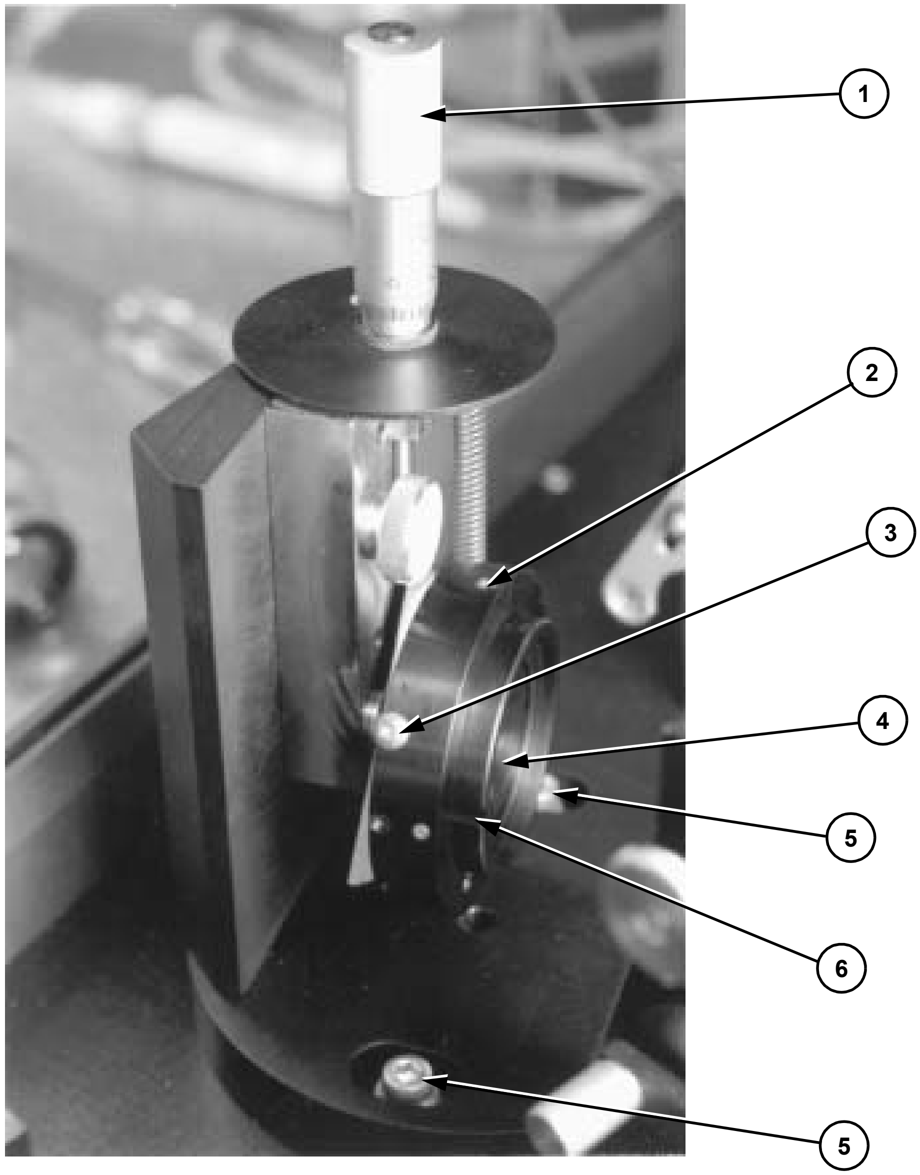


1. BP2 micrometer translation adjustment
2. BP2 Brewster prism rotation adjust
3. BP2 assembly setscrews (not visible in Figure)
4. Brewster prism (BP2)
5. M7 mount assembly (refer to Figure 3-6)
6. Pump beam tube

Figure 3-7. BP2 Prism Controls

Table 3-7. BP2 Prism Controls

CONTROL	FUNCTION
BP2 micrometer translation adjustment	This adjustment determines the amount of glass inserted into the beam path to adjust GVD. The positive or the negative GVD directions are determined by the reading on the micrometer. For more GVD, the number on the micrometer will increase. Procedures for initially positioning the prism are located in Chapter Five, Installation and Alignment, and procedures for adjusting the prism during pulse optimization are located in Chapter Four, Daily Operation.
BP2 Brewster prism rotation adjust	Allows rotational adjustment of BP2. The rotation adjustment sets the prism for zero net angular dispersion. Procedures for these adjustments are located in Chapter Six, Maintenance.
BP2 assembly setscrews	These nylon-tipped setscrews provide tension when adjusting the prism for Brewster's angle. The setscrews must be loosened when removing the BP2 assembly and re-tightened when installing the assembly. BP2 must not be adjusted during operation or maintenance unless specifically directed in a procedure in this operator’s manual.
Brewster prism (BP2)	BP2 and BP1 provide GVD compensation in the laser cavity. BP2 is used to adjust the output pulse width.
Pump beam tube	Confines pump beam and reflections.

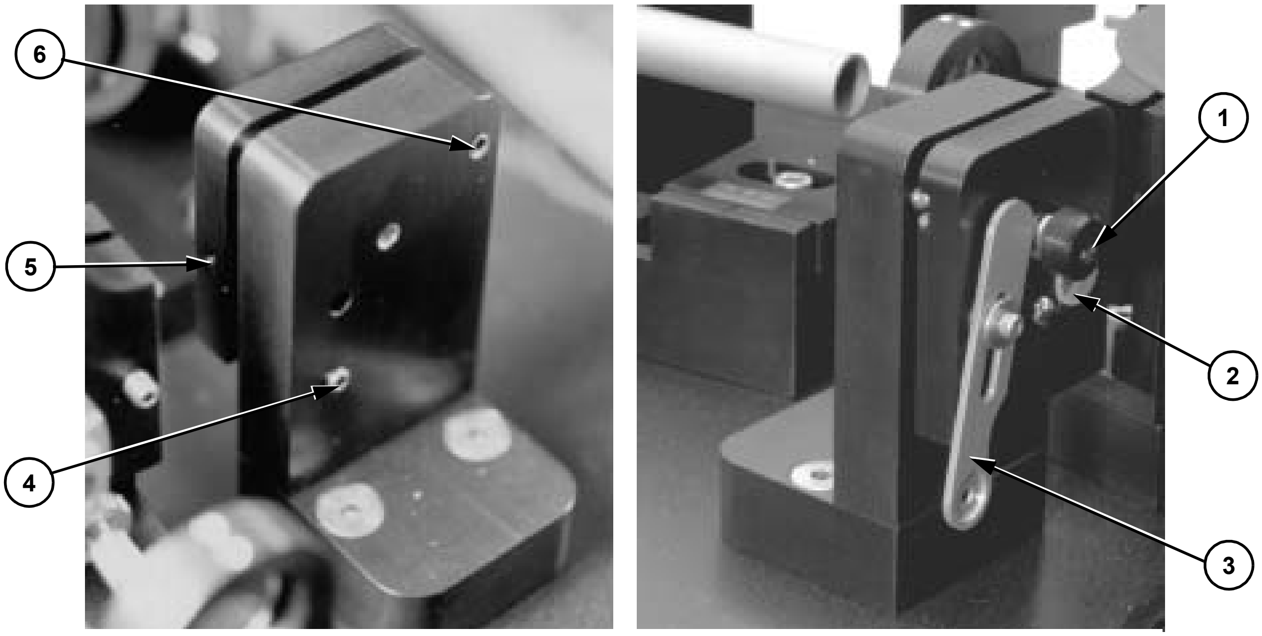


1. BRF micrometer adjust (wavelength tuning)
2. BRF setscrew
3. Button head screw
4. Birefringent filter (BRF)
5. BRF Brewster's angle adjustment screws
6. BRF notch

Figure 3-8. Birefringent Filter Control

Table 3-8. Birefringent Filter Controls

CONTROL	FUNCTION
BRF micrometer adjust	Allows for tuning the birefringent filter during initial alignment and during daily operation. A tuning chart that indicates the wavelength vs. micrometer setting is provided with each laser.
BRF setscrew	Secures the BRF optic holder in place. Normally not adjusted.
Button head screw	Secures the BRF plate and mount to the outer ring. Used to remove BRF.
Birefringent filter	The BRF provides smooth laser cavity tuning within each tuning order. Refer to the tuning chart (supplied with the laser) that indicates wavelength vs. micrometer setting.
BRF Brewster's angle adjustment screws (2)	Loosening the two Allen head screws allows adjusting the BRF for Brewster's angle with respect to the optical path. Used when switching from 1-plate BRF (femtosecond operation) to 3-plate BRF (picosecond operation). This is a factory adjustment and readjustment is not normally required.
BRF notch	The notch when in the "2 O'clock" position (Figure 5-3) generally indicates the primary tuning order. The laser tuning chart (supplied with the system) is the more accurate indication of operating wavelength.

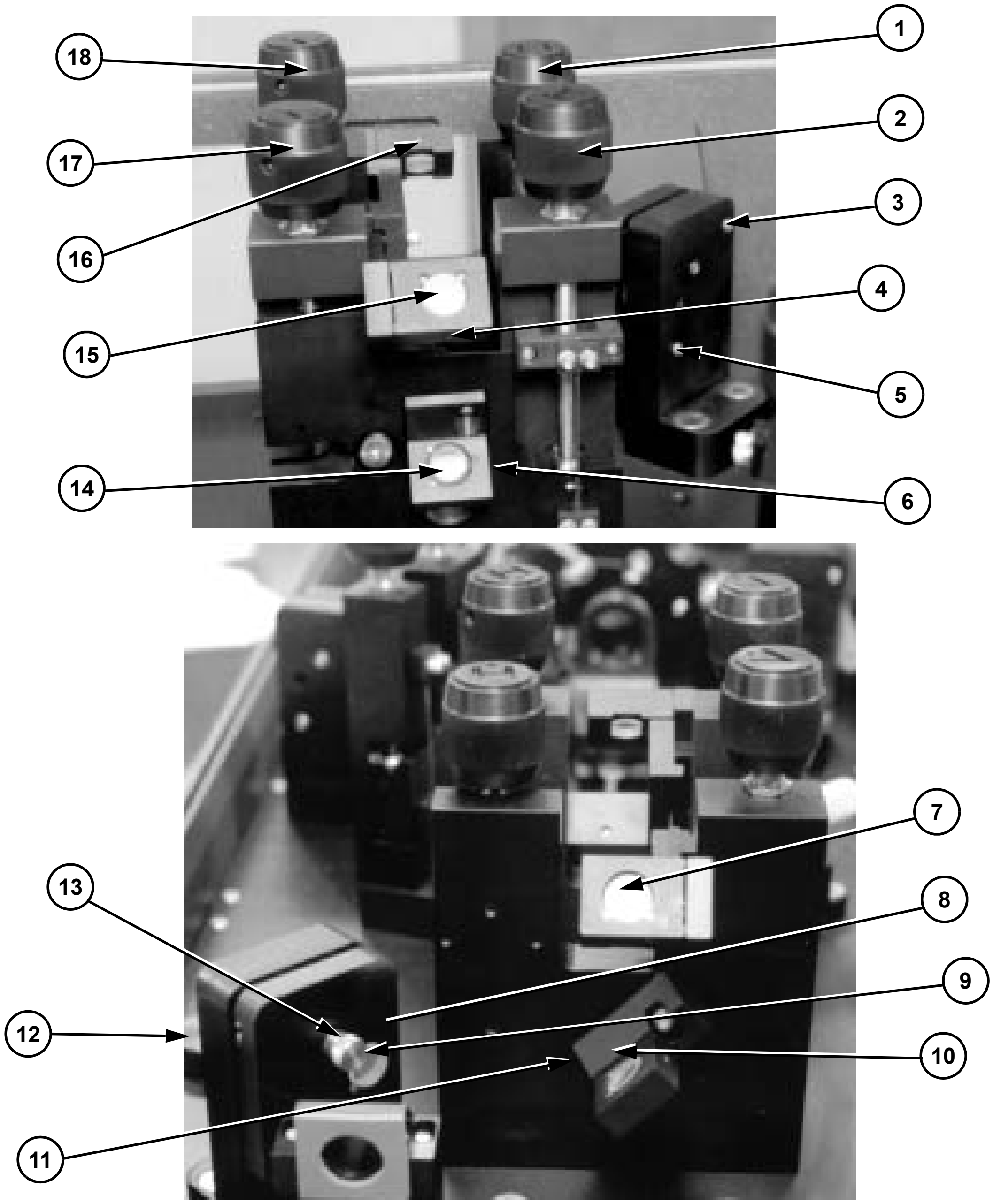


1. M2 tensioning screw
2. M2 optic
3. M2 alignment aperture
4. M2 vertical tilt angle control
5. M2 optic setscrew
6. M2 horizontal tilt angle control

Figure 3-9. M2 Controls

Table 3-9. M2 Controls

CONTROL	FUNCTION
M2 tensioning screw	Determines the amount of pressure required to adjust M2 vertical and horizontal tilt angle controls. This adjustment is performed at the factory and no further adjustments are necessary.
M2 optic	Flat optic in the main cavity.
M2 alignment aperture	The alignment aperture is shown in Figure 3-9 in the open position (out of the beam path) which is the normal operating position. During full alignment, the aperture is positioned over the optic to allow steering the fluorescent spot (or beam) from the crystal into the aperture and to allow steering the retro-reflection from the output coupler into the aperture.
M2 vertical tilt angle control	Changes the vertical tilt angle of the fluorescent spot (or beam). Adjustment results can be seen on the output coupler.
M2 optic setscrew	Secures M2 optic in the optic mount assembly.
M2 horizontal tilt angle control	Changes the horizontal tilt angle of the fluorescent spot (or beam). Adjustment results can be seen on the output coupler.

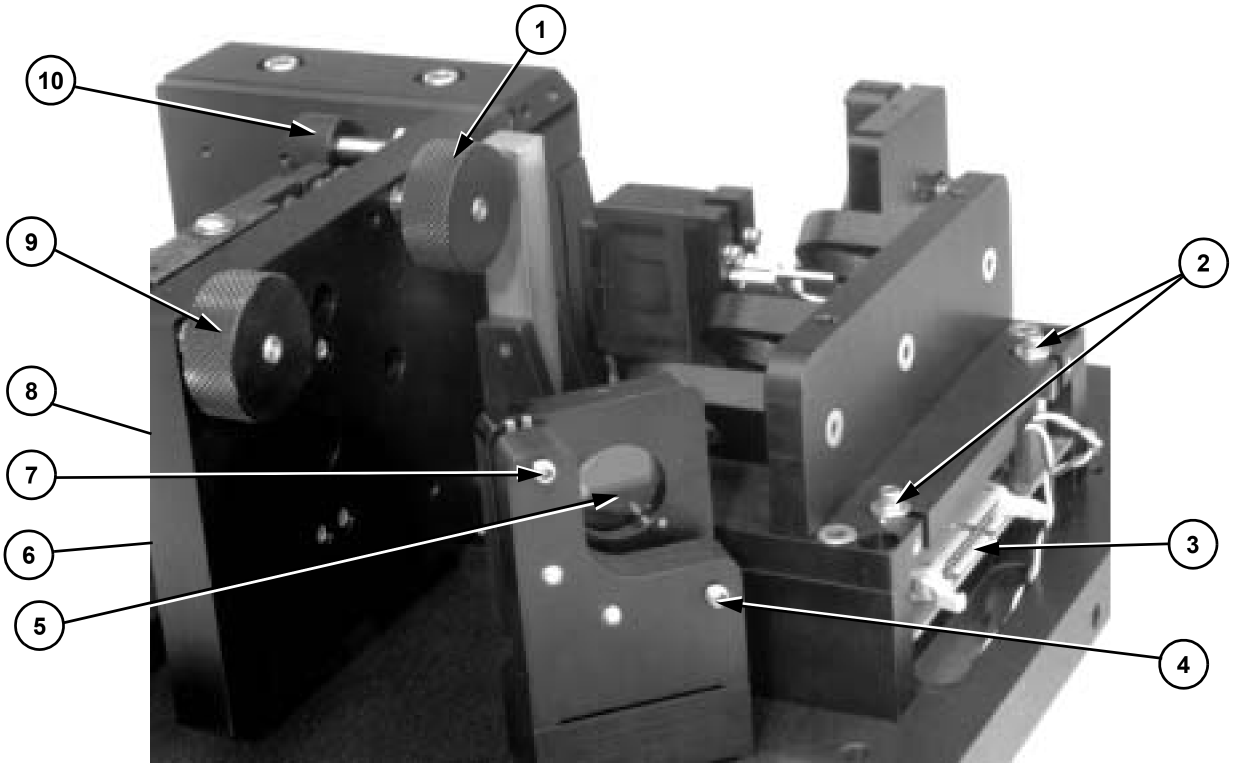


1. P1/P2 horizontal tilt angle control
2. P3/P4 horizontal tilt angle control
3. P0 horizontal tilt angle control
4. P3 optic setscrew
5. P0 vertical tilt angle control
6. P4 optic setscrew
7. P2 pump optic
8. P0 optic setscrew (not visible in photo)
9. P0 pump optic
10. P1 optic setscrew
11. P1 pump optic
12. Laser head height and leveling adjustment screws (2)
13. P0 tensioning screw
14. P4 pump optic
15. P3 pump optic
16. P2 optic setscrew
17. P3/P4 vertical tilt angle control
18. P1/P2 vertical tilt angle control

Figure 3-10. Pump Optic Controls

Table 3-10. Pump Optic Controls

CONTROL	FUNCTION
P2 horizontal tilt angle control	Changes the horizontal and vertical tilt angle of pump optic P2. Controls the angle of the pump beam with respect to cavity axis. Controls are used during initial alignment.
P3/P4 horizontal tilt angle control	Changes the horizontal and vertical tilt angle of the P3 and P4 pump optics. Controls lateral position of the pump beam with respect to cavity axis. Controls are used during alignment and power optimization.
P0 horizontal tilt angle control	Changes the horizontal tilt angle of pump optic P0. Controls are used only during initial alignment.
P0 through P4 setscrews	Secures P0 through P4 pump optics to their respective mounts.
P0 vertical tilt angle control	Changes the vertical tilt angle of pump optic P0. Controls are used only during initial alignment.
P1 through P4 pump optics	Pump beam steering optics.
P0 optic	P0 is a pump beam fold mirror that allows straight-in pumping. P0 is not used for left-side and right-side pumping.
Laser head height and leveling adjustment screws (2)	Allows leveling and adjusting the laser head. Height adjustment and height leveling is accomplished by loosening the knurled retainer, then using a screwdriver to adjust the screw. The height and leveling adjustments are performed at the factory. No further adjustments are required.
P0 tensioning screw	Determines the amount of pressure required to adjust P0 vertical and horizontal tilt angle controls. This adjustment is performed at the factory and no further adjustments are necessary.
P3/P4 vertical tilt angle control	Changes the vertical tilt angle of the P3 and P4 pump optics. Controls lateral position of pump beam with respect to cavity axis. Controls are used during alignment and power optimization.
P2 vertical tilt angle control	Changes the vertical tilt angle of the P2 pump optic. Controls the angle of pump beam with respect to cavity axis. Controls are used during initial alignment.

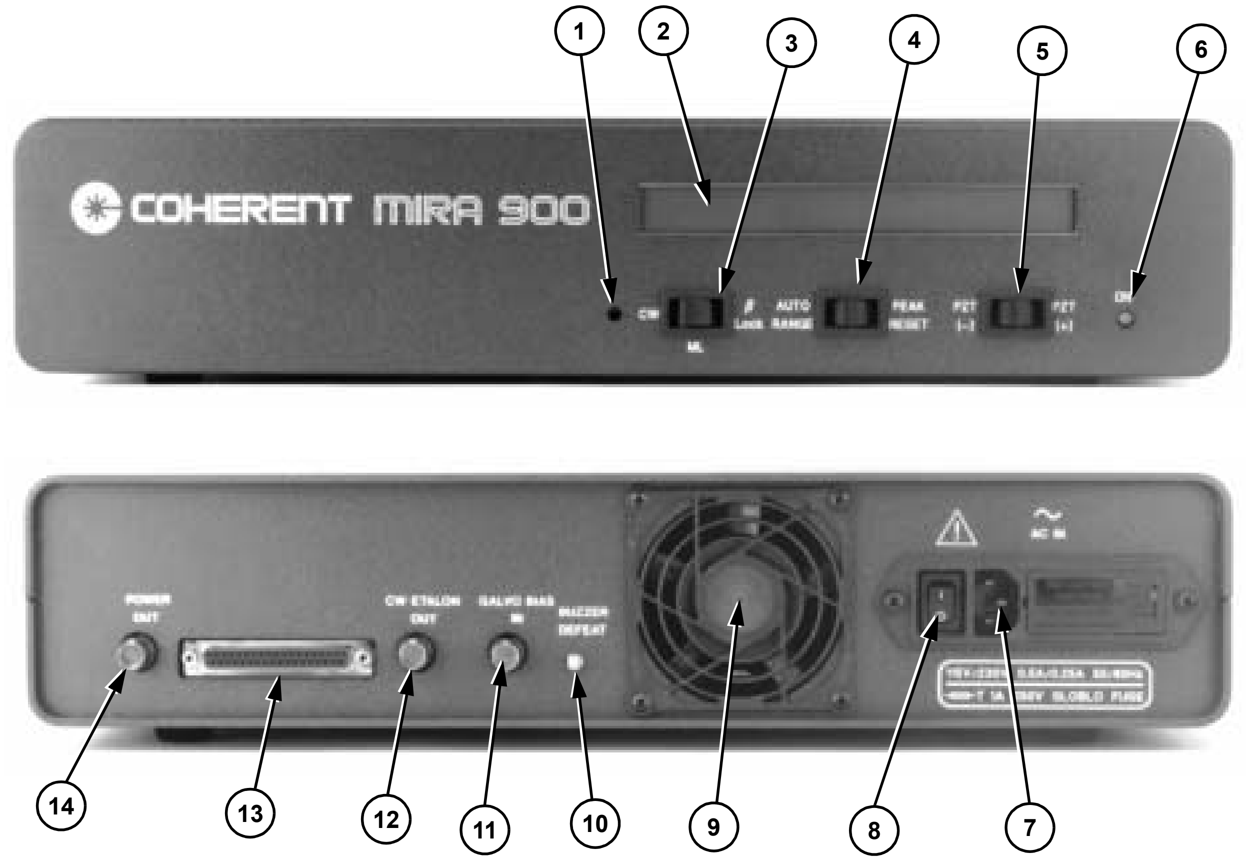


1. Output coupler (M1) horizontal tilt angle control
2. Screws (4)
3. Head board
4. Beamsplitter (BS1) horizontal tilt angle control
5. Beamsplitter BS1
6. Output Coupler M1 (refer to Figure 3-4)
7. Beamsplitter (BS1) vertical tilt angle control
8. M1 setscrew (refer to Figure 3-4)
9. Output coupler (M1) vertical tilt angle control
10. Cavity length adjustment

Figure 3-11. Output Coupler/Beamsplitter/Head Board/Cavity Length Controls

Table 3-11. Output Coupler/Beamsplitter/Head Board/Cavity Length Controls

CONTROL	FUNCTION
Output coupler (M1) horizontal tilt angle controls	Changes the horizontal tilt angle adjustment of the output coupler to align the cavity.
Screws (4)	Secures the head board to the laser head.
Head board	Three photodiodes and circuitry to process information from the photodiodes are located on this board. The photodiodes provide the following: • A sync output to allow synchronizing the output pulse to an experiment. Input from beamsplitter BS2 (refer to Figure 3-20). • CW content information for display on the controller. Input from beamsplitter BS4 (refer to Figure 3-20). • Average output power for display on the controller. Input from beamsplitter BS3 (refer to Figure 3-20).
Beamsplitter (BS1) horizontal tilt angle controls	Changes the horizontal tilt of the beamsplitter that steers a portion of the output beam onto the three beamsplitters (Figure 3-20; items 1, 3, and 4) that provide input to the photodetectors located on the head board.
Beamsplitter BS1	Provides a small portion of the output beam to the photodetectors on the head board via beamsplitters BS2 through BS4.
Output coupler M1	Partially transmitting cavity end mirror that allows a portion of the output beam to exit the cavity.
Beamsplitter (BS1) vertical tilt angle controls	Changes the vertical tilt of the beamsplitter that steer a portion of the output beam onto the three beamsplitters (Figure 3-20; items 1, 3, and 4) that provide input to the photodetectors located on the head board.
M1 setscrew	Secures M1 optic in the optic mount assembly.
Output coupler (M1) vertical tilt angle controls	Changes the vertical tilt angle adjustment of the output coupler to align the cavity.
Cavity length adjustment	Changes the pulse repetition rate of the laser approximately $\pm$ 0.5 MHz.

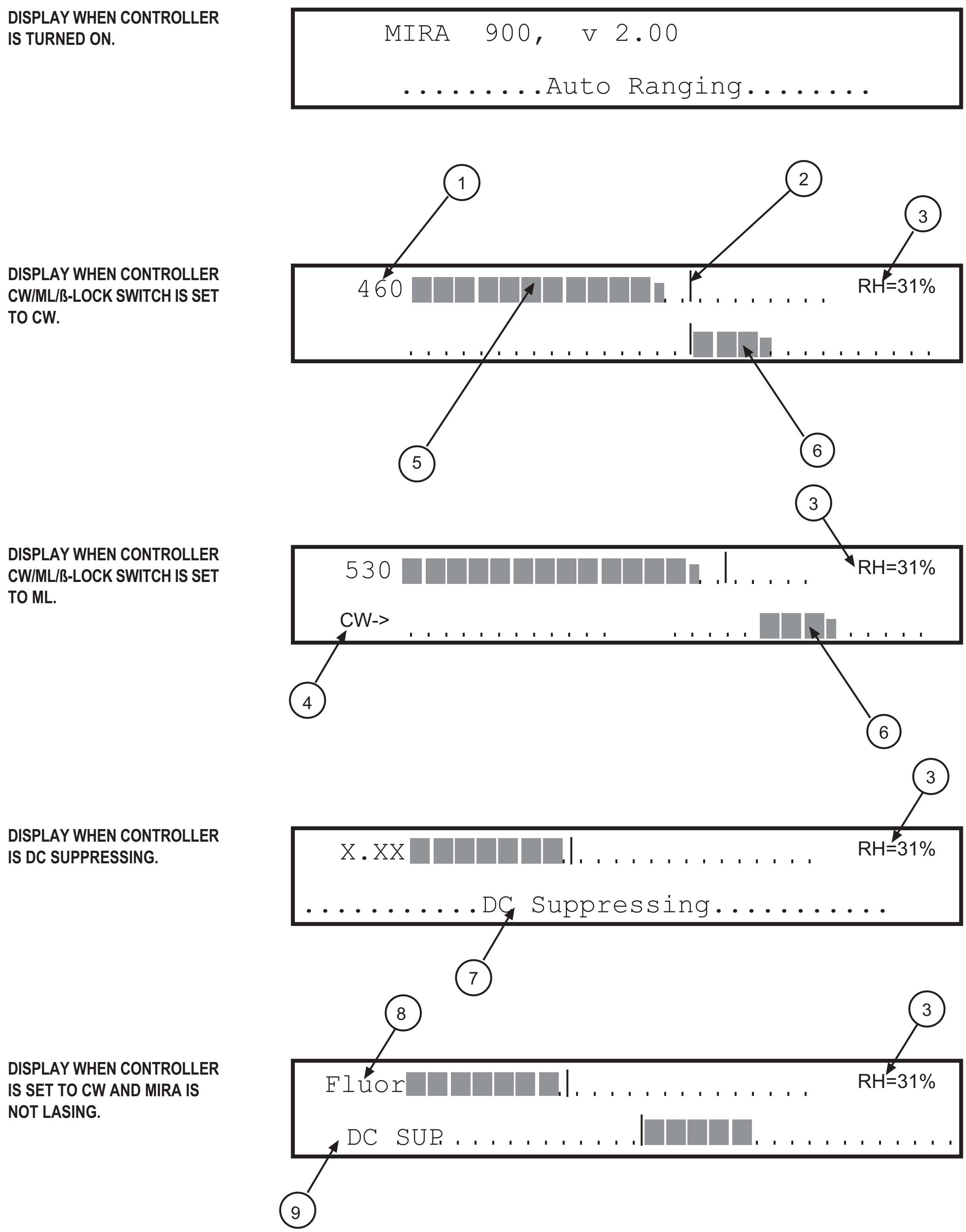


1. View angle adjust
2. LCD display
3. CW/ML/β-Lock select switch
4. AUTO RANGE / PEAK RESET select switch
5. PZT (–) / PZT (+) select
6. ON indicator LED
7. AC In
8. ON/OFF Switch
9. Fan
10. BUZZER DEFEAT switch
11. GALVO BIAS IN BNC connector
12. CW ETALON OUT BNC connector
13. Head board connector
14. POWER OUT BNC connector

Figure 3-12. Controller Controls and Indicators

Table 3-12. Controller Controls and Indicators

CONTROL	FUNCTION
CONTROLLER FRONT PANEL	
View angle adjust	This adjustment allows the LCD display to be adjusted for the best viewing angle.
LCD display	This two-line, 80-character LCD display provides cavity and diagnostic information relating to the Mira Optima. Refer to Figure 3-13 for an explanation of the displays.
CW/ML/β-Lock select switch	Allows selection between ML, β-Lock and CW modes. β-Lock is only used for picosecond operation.
AUTO RANGE	Allows the power display to automatically switch (auto range) to the next higher power scale. The controller produces an audible buzz when the display auto-ranges to a higher scale. If desired, the buzzer can be turned off using the BUZZER DEFEAT on the controller rear panel. The power display will not auto-range to a lower scale. The switch must be toggled to the AUTO RANGE position to change to a lower scale.
PEAK RESET	The toggle position (switch does not remain in the PEAK RESET position when released) allows the peak marker on the display to be reset to current power level.
PZT (–) / PZT (+) select switch	Changes the voltage on the GTI if the laser is configured for picosecond operation. In the ML mode this switch adjusts the Piezo-electric transducer (PZT) voltage directly. In the β-Lock mode it adjusts the servo lock-point (which varies the PZT voltage).
ON indicator	Indicates that the Mira Optima controller has been turned on.
CONTROLLER REAR PANEL	
AC In	AC power cord connector.
ON/OFF Switch	Applies 115 (or 230) volts to the Mira Optima controller.
Fan	Provides air cooling for the controller.
BUZZER DEFEAT	Allows the buzzer to be turned off or on. The buzzer indicates that the power display has changed automatically to a higher scale as dictated by the auto-ranging feature.
GALVO BIAS IN BNC connector	Provides external control of the starter galvo to make small changes to the cavity length.
CW ETALON OUT BNC connector	Provides an analog voltage output related to the CW component.
Head board connector	Provides an interface connection to the head board located in the Mira Optima laser head.
POWER OUT BNC connector	Analog output proportional to average power.

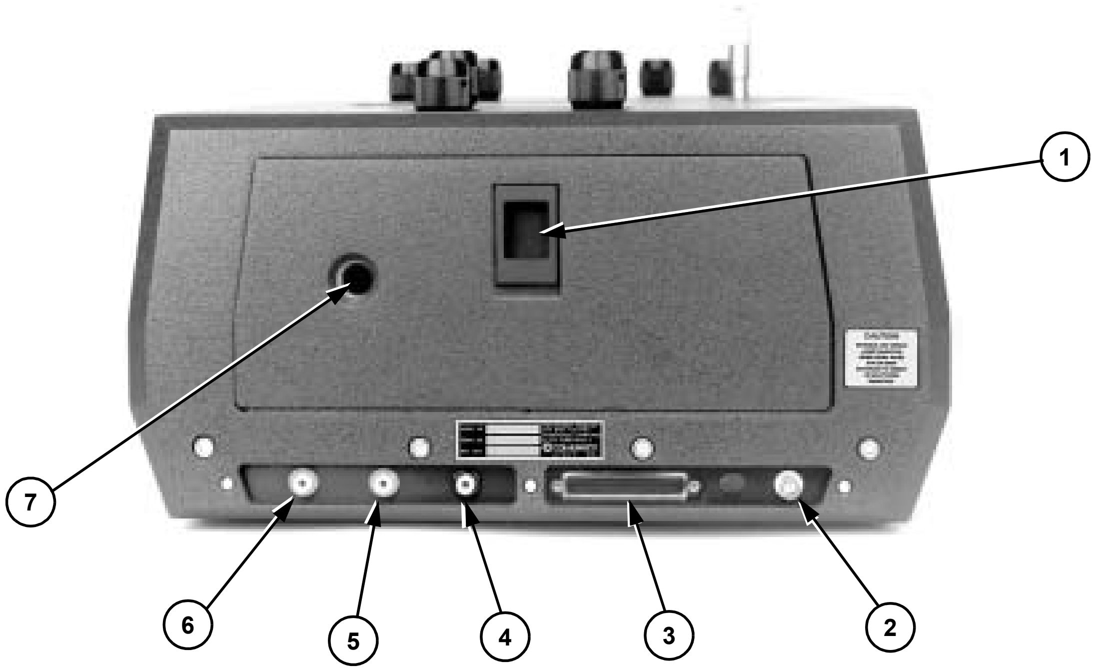


Note: The controller beeps once when auto-ranging.
The controller beeps three times upon startup if a RAM error occurred.

Figure 3-13. Controller Displays

Table 3-13. Controller Displays

KEY	DESCRIPTION
1	The count is proportional to the output power at normal output levels.
2	Peak power marker reflecting the maximum power achieved since last peak reset. The marker can be reset by toggling the AUTO RANGE/PEAK RESET switch to PEAK RESET.
3	RH indicates the relative humidity in the laser cavity.
4	Displays CW component in output beam, usually indicating that the slit width must be decreased.
5	Bar graph displays average power output.
6	Expanded average power display, showing change in power since the last AUTO RANGE or PEAK RESET. When the AUTO RANGE/PEAK RESET switch is toggled to AUTO RANGE, the expanded average power display resets without resetting the peak indicator. Power decreases and increases are indicated by an outlined bar.
7	DC Suppression increases the display sensitivity. Maximum sensitivity is desired when using the display to observe fluorescence. The controller DC Suppression feature can only be activated when DC SUP is displayed in the lower left corner of the display. See Key 2. In this mode it may be necessary to reduce room lighting.
8	Fluor indicates the laser is not lasing and that the fluorescence is being seen by the detectors.
9	DC SUP indicates that DC Suppression can be initiated by holding down the AUTO RANGE/ PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. DC SUP will appear when the Mira Optima is not lasing, the controller CW/ML/β-Lock switch is set to CW, and the AUTO RANGE/PEAK RESET switch is toggled to AUTO RANGE.

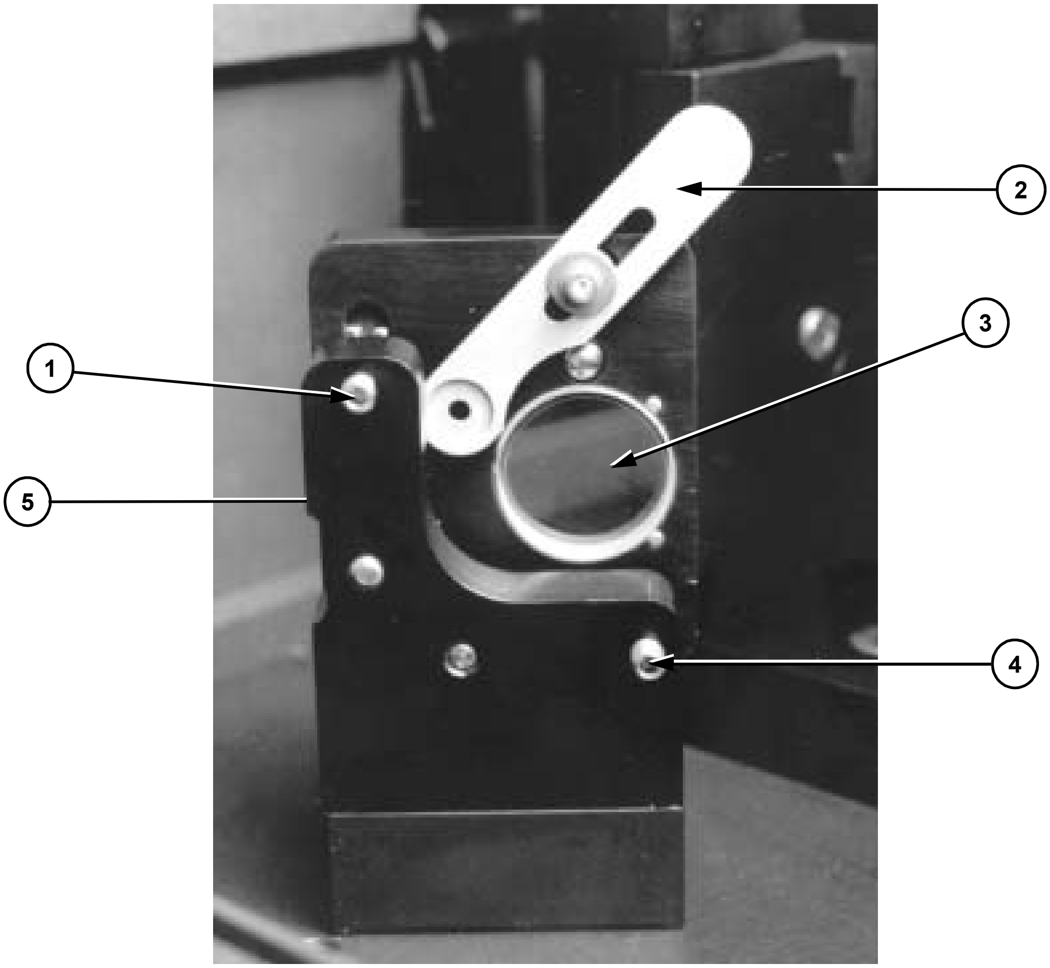


1. Cover latch
2. Fast diode output (sync out)
3. Laser head connector
4. Nitrogen purge connector
5. Water IN/OUT connector
6. Water IN/OUT connector
7. Pump beam input aperture

Figure 3-14. Laser Head Rear Interface Connectors

Table 3-14. Laser Head Rear Interface Connectors

CONTROL	FUNCTION
Cover latch	Allows the laser head rear cover to be opened.
Fast diode output (sync out)	Output for synchronizing external equipment with the Mira Optima output pulse. This output can also be used to monitor the output pulse with an oscilloscope. Refer to Figure 5-3.
Laser head connector	Provides and interface connection to the head board 37-pin connector located on the rear of the controller.
Nitrogen purge connector	Tubing connector for a nitrogen purge for the Mira Optima laser head. Do not connect water to this line.
Water IN/OUT connectors	Hose connectors for the crystal cooling water needed. Either connector can be used as the IN or OUT.
Pump Beam input aperture (3)	The input aperture is a Brewster window that allows the pump beam to enter the laser head while allowing the covers to provide a tight seal. There are two additional apertures for left side and right side pumping. The input aperture illustrated on the end cover is used when the Mira Optima is configured for straight-in pumping.

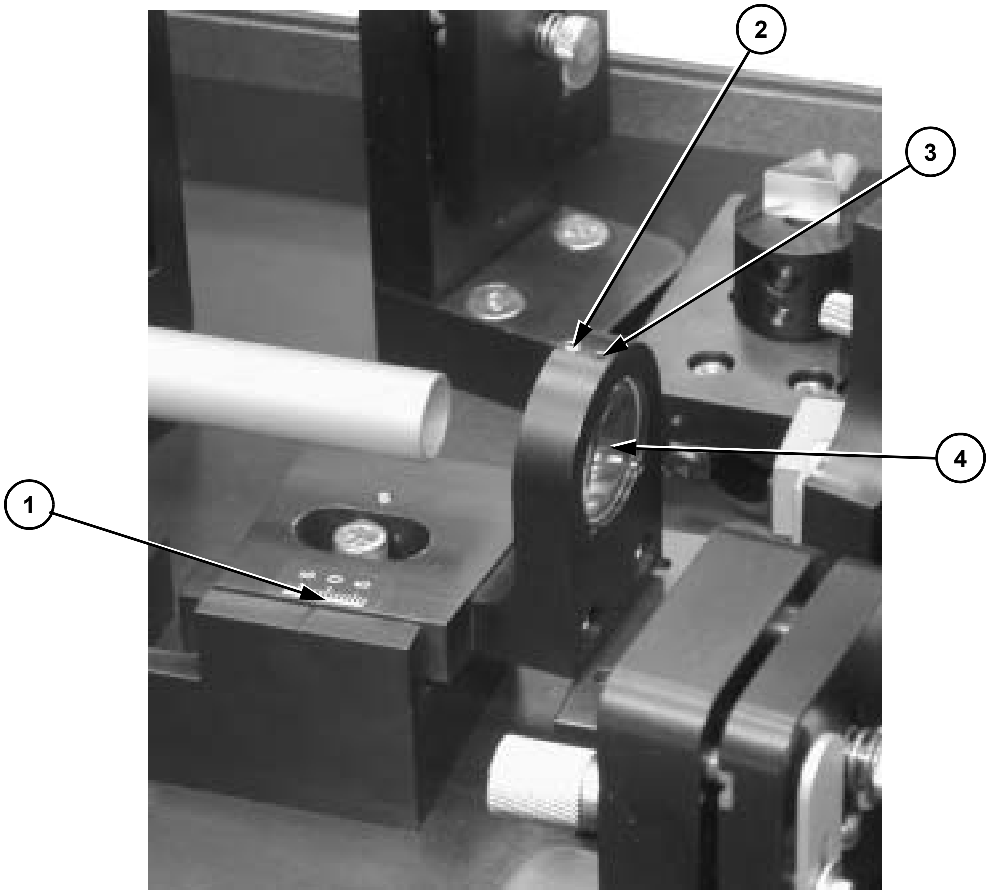


1. M6 vertical tilt angle control
2. M6 alignment aperture
3. M6 optic
4. M6 horizontal tilt angle control
5. M6 optic setscrew

Figure 3-15. M6 Controls

Table 3-15. M6 Controls

CONTROL	FUNCTION
M6 vertical tilt angle control	Changes the vertical tilt of the M6 optic during alignment.
M6 alignment aperture	The alignment aperture is shown in Figure 3-15 in the open position (out of the beam path) which is the normal operating position. During full alignment, the aperture is positioned over the optic to allow steering the fluorescent spot (or beam) into the aperture and to allow steering the retro-reflection from M7 into the aperture.
M6 optic	Flat fold mirror located in the main cavity.
M6 horizontal tilt angle control	Changes the horizontal tilt of the M6 optic during alignment.
M6 optic setscrew	Secures the M6 optic in the mount assembly.

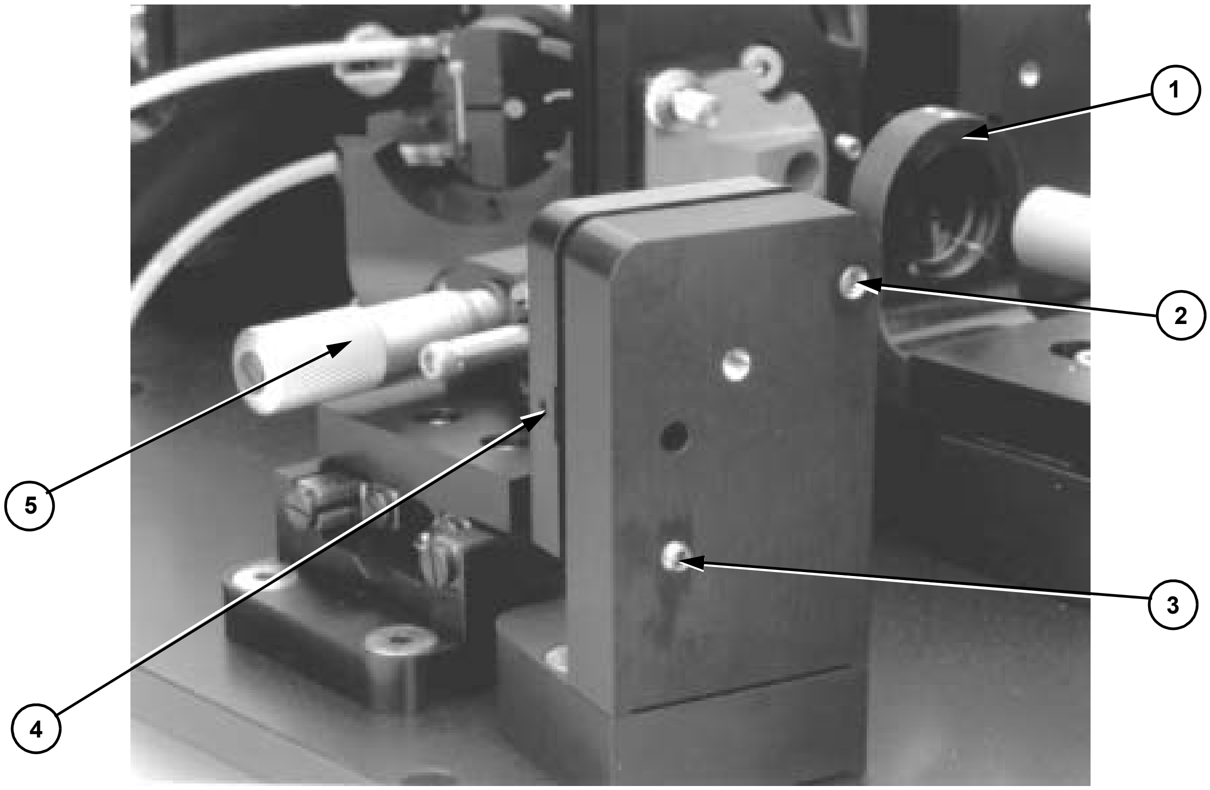


1. L1 mount index marker
2. L1 optic setscrew
3. L1 alignment aperture setscrew
4. Focusing lens L1

Figure 3-16. Focusing Lens L1 Controls

Table 3-16. Focusing Lens L1 Controls

CONTROL	FUNCTION
L1 mount index marker	Indicates the position of the L1 mount during factory alignment. This is not a user adjustment.
L1 optic setscrew	Secures the L1 optic in the L1 mount.
L1 Alignment aperture setscrew	Secures the L1 alignment aperture (part of the accessory kit) in the L1 mount during Mira Optima alignment.
Focusing lens L1	Focuses the pump beam onto the crystal.



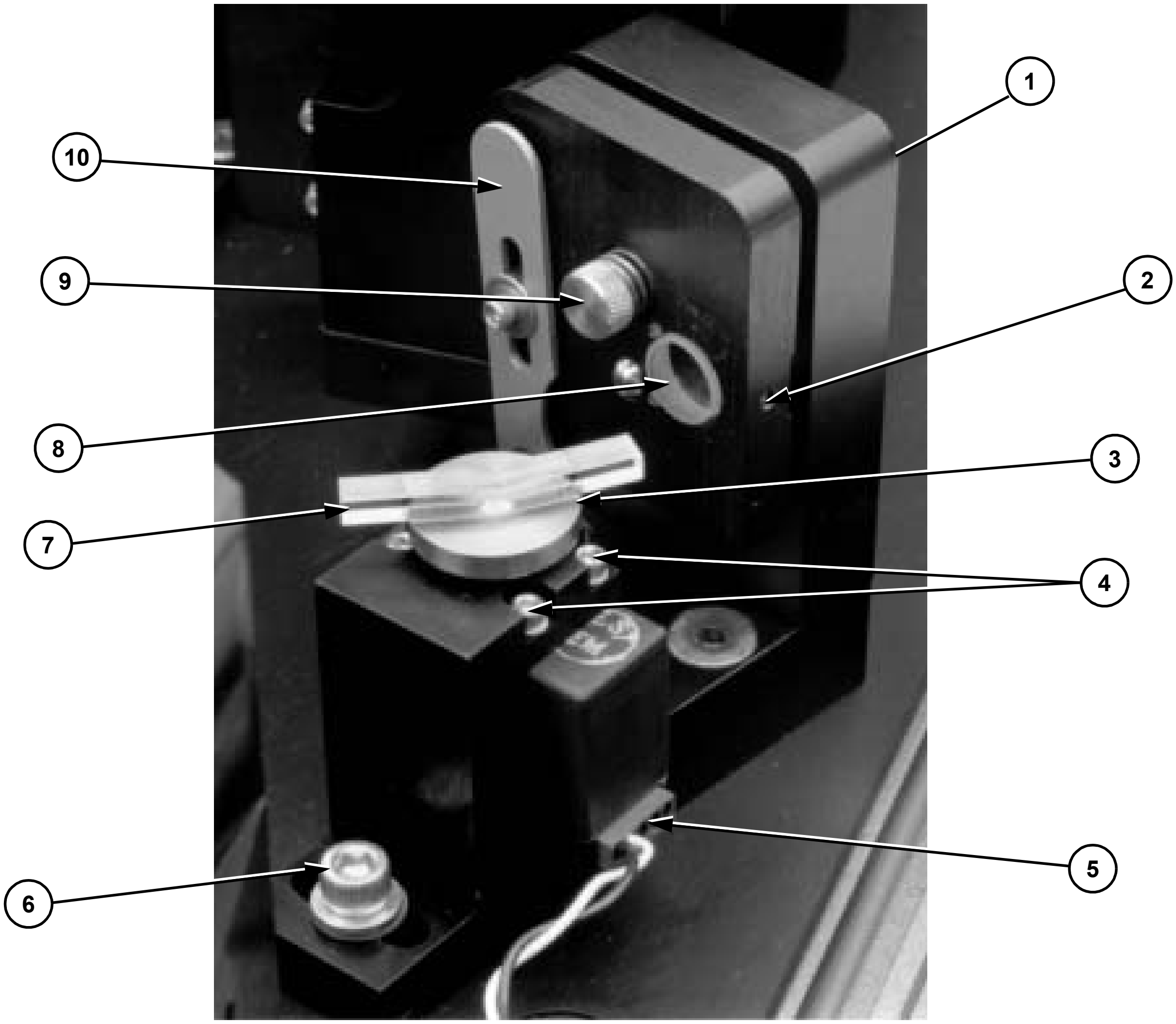
1. L1 mount (refer to Figure 3-16)
2. M8 horizontal tilt angle control
3. M8 vertical tilt angle control
4. M8 optic setscrew
5. BP1 micrometer (refer to Figure 3-2)

Note: Refer to Figure 3-2 for additional M8 controls.

Figure 3-17. M8 Controls

Table 3-17. M8 Controls

CONTROL	FUNCTION
M8 horizontal tilt angle control	Changes the horizontal tilt of the M8 optic during alignment.
M8 vertical tilt angle control	Changes the vertical tilt of the M8 optic during alignment.
M8 optic setscrew	Secures the M8 optic in the mount assembly.



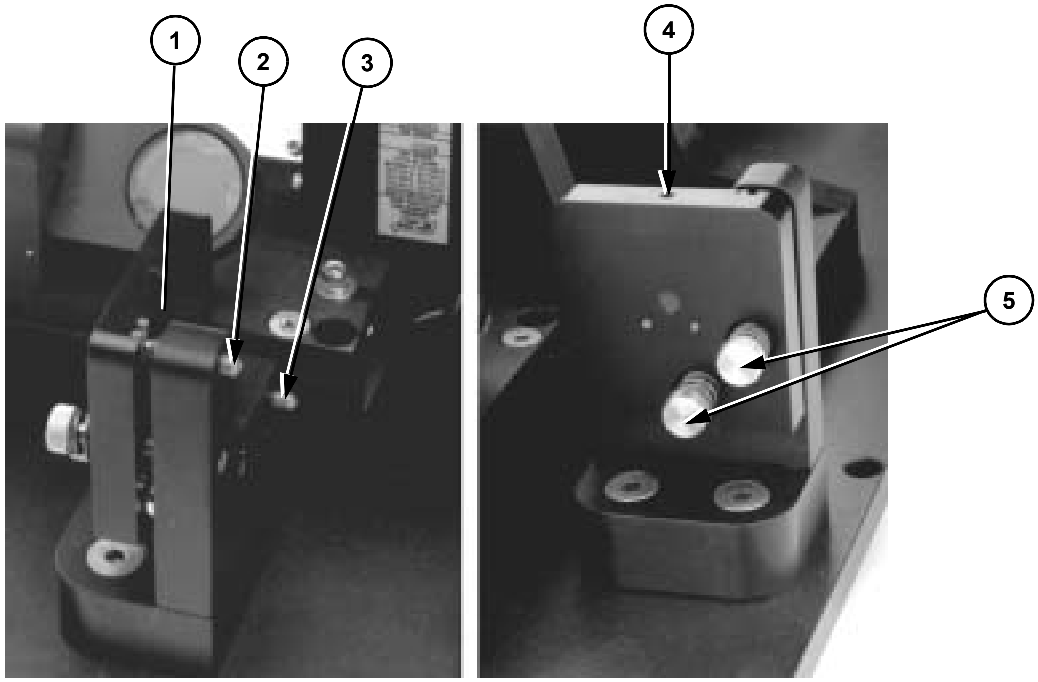
1. M3 vertical and horizontal tilt angle controls (not visible in photo)
2. M3 optic setscrew
3. Setscrews (2)
4. Allen head screws (4)
5. Starter connector
6. Starter assembly Allen head screw
7. Starter assembly butterfly
8. M3 optic
9. M3 tension adjust
10. M3 alignment aperture

Note: Refer to Figure 3-4 for additional M3 controls.

Figure 3-18. Starter Assembly/M3 Controls

Table 3-18. Starter Assembly/M3 Controls

CONTROL	FUNCTION
M3 vertical and horizontal tilt angle controls	Changes the vertical and horizontal tilt angle of optic M3 during alignment.
M3 optic setscrew	Secures M3 optic in the optic mount assembly.
Setscrews	Secures the butterfly and butterfly mount to the galvo shaft.
Allen head screw (4)	Secures the starter galvo to the mount assembly.
Starter connector	Supplies the drive signal to the butterfly galvo.
Starter assembly Allen head screw	Allows adjustment of the starter assembly so, when not activated, the butterfly is positioned at Brewster's angle with respect to the beam path.
Starter assembly butterfly	The butterfly mounted on the starter assembly initiates mode-locked operation. The butterfly oscillates when a drive signal is applied to the starter assembly galvo. The oscillation causes rapid small changes to the cavity length. The position of the butterfly can also be changed slightly by applying an external voltage to the GALVO BIAS BNC connector on the rear of the controller.
M3 optic	Flat optic in the main cavity.
M3 tensioning screw	Determines the amount of pressure required to adjust M3 vertical and horizontal tilt angle controls. This adjustment is performed at the factory and no further adjustments are necessary.
M3 alignment aperture	The alignment aperture is shown in Figure 3-18 in the open position (out of the beam path) which is the normal operating position. During full alignment, the aperture is positioned over the optic to allow steering the fluorescent spot (or beam) into the aperture.

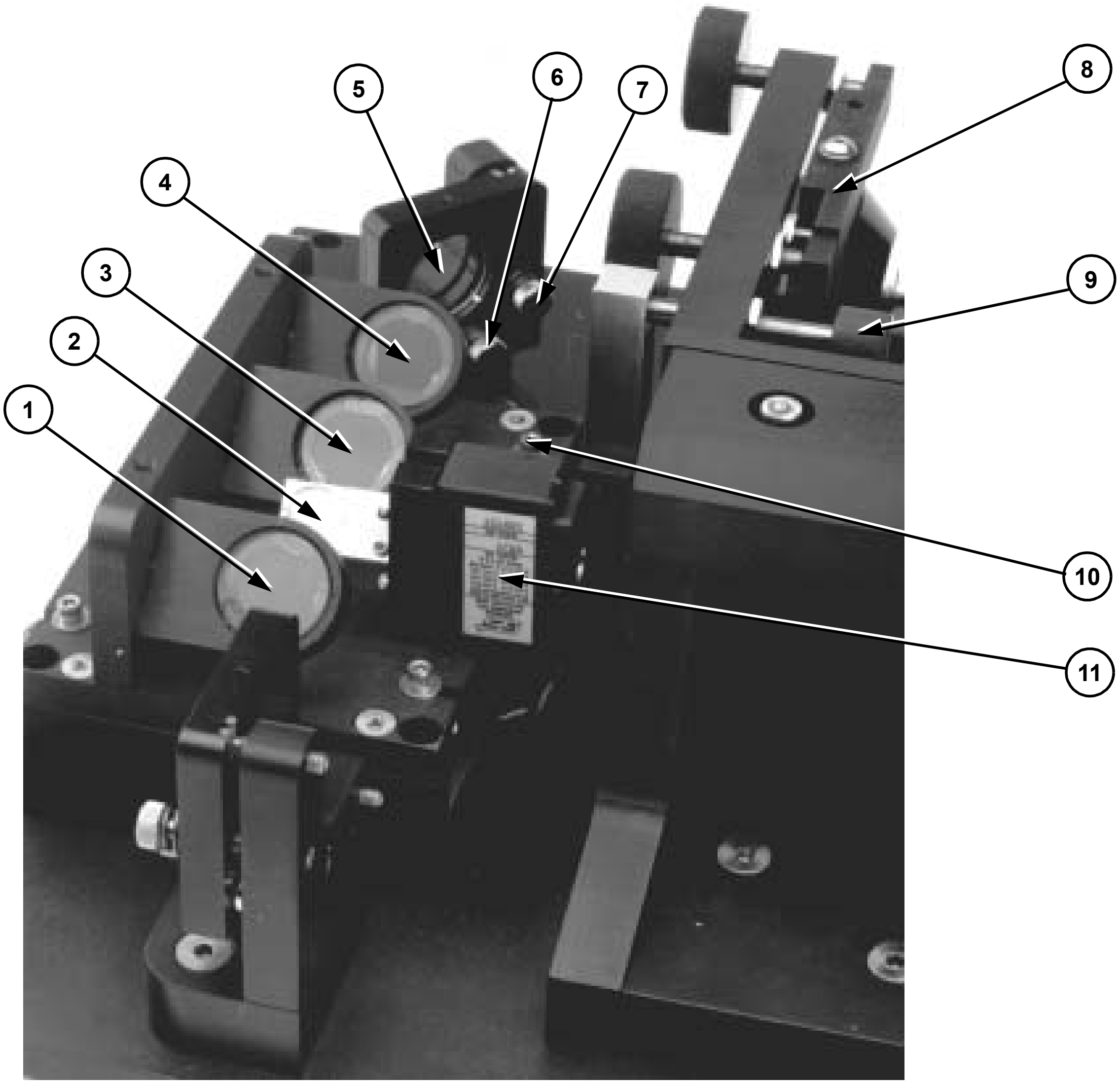


1. M9 optic (not visible)
2. M9 vertical tilt angle adjust
3. M9 horizontal tilt angle adjust
4. M9 optic setscrew
5. Tensioning screws

Figure 3-19. M9 Controls

Table 3-19. M9 Controls

CONTROL	FUNCTION
M9 optic	Flat end mirror in the auxiliary cavity.
M9 vertical tilt angle control	Changes the vertical tilt of the M9 optic during alignment.
M9 horizontal tilt angle controls	Changes the horizontal tilt of the M9 optic during alignment.
M9 optic setscrew	Secures M9 optic in the optic mount assembly.
Tensioning screws	Determines the amount of pressure required to adjust M9 vertical and horizontal tilt angle controls. This adjustment is performed at the factory and no further adjustments are necessary.

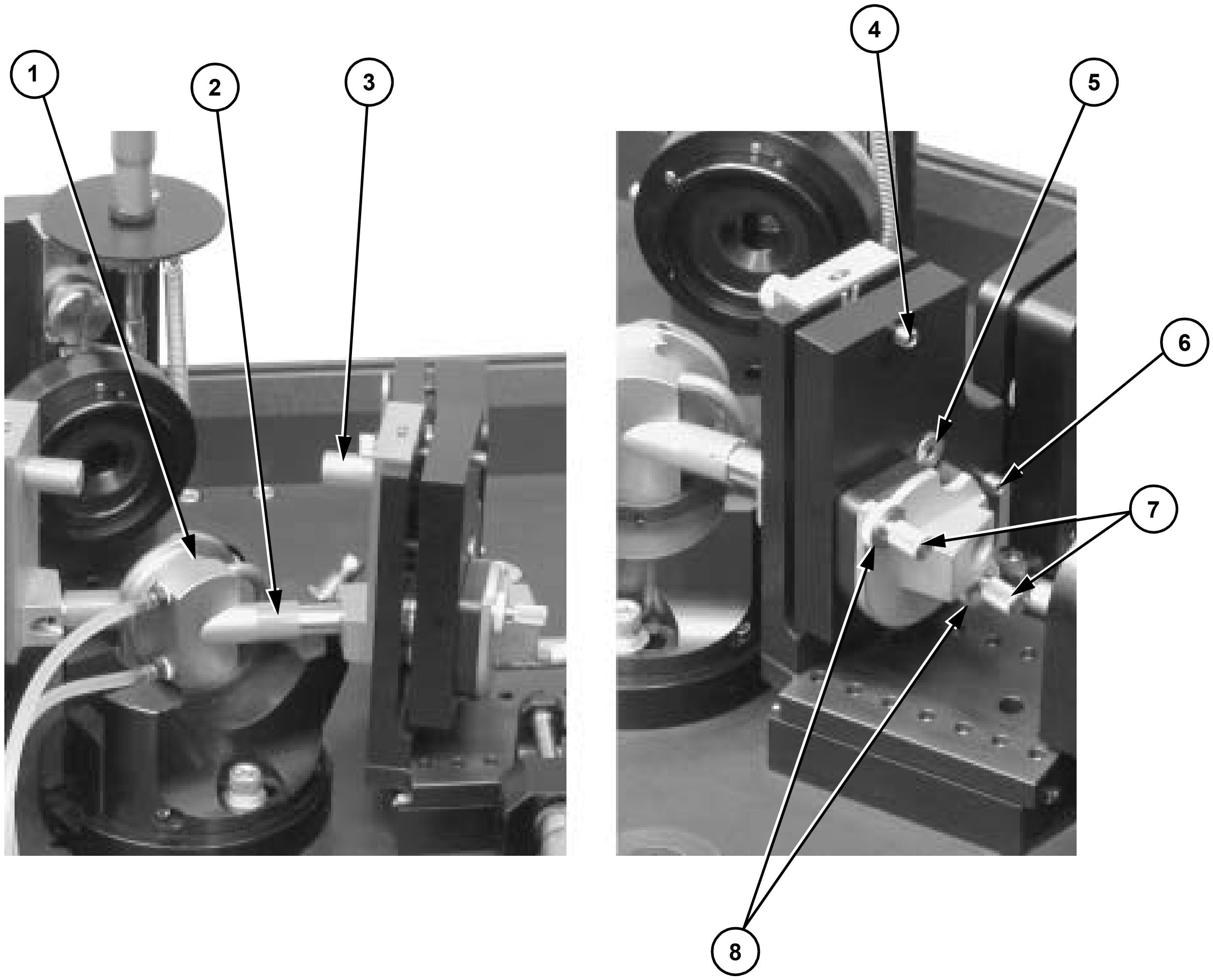


1. CW beamsplitter BS4
2. Etalon
3. Average power beamsplitter BS3
4. Fast photodiode beamsplitter BS2
5. Beamsplitter BS1
6. BS1 vertical tension adjust
7. BS1 horizontal tension adjust
8. Output coupler lever arm
9. Cavity length adjustment control
10. Screws (4)
11 Etalon galvo

Figure 3-20. Beamsplitters

Table 3-20. Beamsplitters

CONTROL	FUNCTION
CW beamsplitter BS4	Provides a portion of the output beam to the CW detector located on the head board. The detector provides CW information for display on the controller.
Etalon	Provides the CW component of the output beam to the controller via the CW beamsplitter and photodiode on the laser head board. The presence of CW during normal mode-locked operation typically indicates the slit is not properly adjusted.
Average power beamsplitter BS3	Provides a portion of the output beam to the average power detector located on the head board. The detector provides average output power information for the controller display.
Fast photodiode beamsplitter BS2	Provides a portion of the output beam to the fast photo diode located on the head board. The fast photodiode provides a sync output to allow synchronizing the output pulse to an experiment.
Beamsplitter BS1	Provides a small portion of the output beam to the photodetectors on the head board via beamsplitters BS2 through BS4.
BS1 vertical and horizontal tension adjust screws	Determines the amount of pressure required to adjust BS1 vertical and horizontal tilt angle controls. This adjustment is performed at the factory and no further adjustments are necessary.
Cavity length adjustment control	Changes the pulse repetition rate of the laser approximately ± 0.5 MHz.
Screws (4)	Secures the galvo to the mount.
Etalon galvo	Used to oscillate the etalon.



1. Titanium:sapphire assembly
2. Beam tube assembly M4/crystal
3. Knurled thumbscrew (beam tube assembly)
4. M4 vertical tilt angle control
5. M4 tensioning screw
6. M4 horizontal tilt angle control
7. M4 optic retaining thumbscrews (2)
8. M4 pump beam block thumbnuts (2)

Note: Refer to Figure 3-3 for additional crystal controls.

Figure 3-21. M4 Controls

Table 3-21. M4 Controls

CONTROL	FUNCTION
Titanium: sapphire assembly	Houses the titanium:sapphire crystal and provides for the cooling of the crystal.
Beam tube assembly M4/crystal	Provides protection from dust for the crystal. Confines stray reflections between crystal and M4. Note the position of the telescoping beam tube. The entire assembly can be removed by loosening the thumbnuts. Removal is unnecessary unless directed by a procedure in this operator's manual.
Knurled thumbscrews (beam tube assembly)	Secures the beam tube assembly to their mounts.
M4 vertical tilt angle control	Changes the vertical tilt of the M4 optic during alignment.
M4 tensioning screw	Determines the amount of pressure required to adjust M4 vertical and horizontal tilt angle controls. This adjustment is performed at the factory and no further adjustments are necessary.
M4 horizontal tilt angle controls	Changes the horizontal tilt of the M4 optic during alignment.
M4 optic retaining thumbscrews (2)	Secures the M4 optic assembly in the mount. Normally, M4 should only be removed for optic replacement. M4 can be cleaned in place.
M4 pump beam block thumbnuts (2)	Secures the pump beam block to the M4 mount.

OPERATOR'S MANUAL

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CHAPTER FOUR
DAILY OPERATION

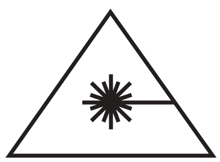
COHERENT

Introduction

This chapter contains procedures for daily turn-on after temporary or long term shutdown.

The procedures contained in this chapter assume the user is familiar with the pump laser. Refer to the pump laser operator's manual as necessary to perform steps in the following procedures such as location of controls, pump laser startup, setting of output power, etc.

Daily Turn-on



Wear laser safety glasses to protect against the radiation generated from the Mira Optima and the pump laser. Refer to the fact sheets for the specific wavelengths being generated, and to the pump laser operator's manual for safety precautions and wavelengths generated from the pump laser. It is assumed that the operator has read Chapter One, Laser Safety, and is familiar with laser safety practices and the dangers involved.

Both the Mira Optima laser and the pump laser are designed to be operated with the covers in place. Operation of the laser with the protective housing removed will allow access to hazardous visible and invisible radiation. The laser housings should only be opened for the purposes of maintenance and service by trained personnel aware of the hazards involved.

Extreme caution must be observed in operating the laser with the cover removed. There are high-power reflections that may exit at unpredictable angles from the laser head. These beams have sufficient energy density to cause permanent eye damage or blindness.

Perform daily turn-on in accordance with Figure 4-1.

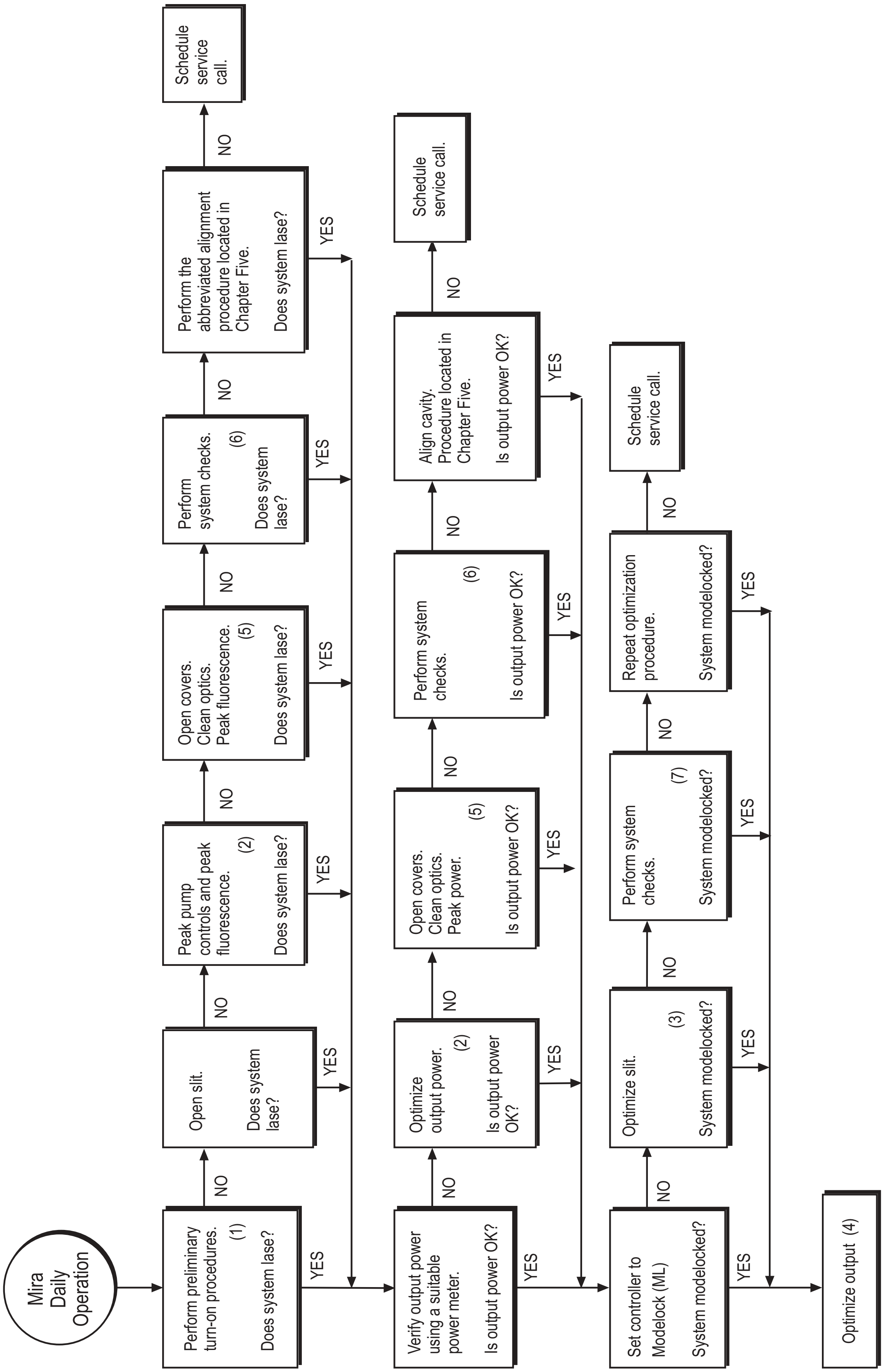


Figure 4-1. Mira Optima Daily Operation

The numbered paragraphs below are keyed to, and supplement the flow chart on Figure 4-1.

[1] The following procedures are intended for use when the system has been completely shutdown, such as overnight. Use the short term turn-on procedures if the system has been temporarily shut down.

Avoid cooling water flow to the titanium:sapphire crystal for long periods when the pump beam is not striking the crystal. Failure to observe this could result in the formation of condensation that could contaminate the crystal.

Avoid operating the Mira Optima laser with the pump beam traveling through the crystal without cooling water turned on. Failure to observe this could result in damage to the crystal.

In summary, in order to avoid crystal damage, turn on the cooling water when the pump beam is striking the crystal and turn off the cooling water when the pump beam is not striking the crystal.

1. Turn the cooling water on for the titanium:sapphire crystal and pump laser.
2. Turn the nitrogen (N_2) on to purge the Mira Optima cavity. Coherent recommends that the cavity be purged with dry N_2 when operating above 870 nm. Between 920 nm and 980 nm, a high-velocity purge for several hours may be required to reduce the cavity humidity to near-zero levels. Also, a dry N_2 purge may be required when operating at 761 ± 5 nm and at 820 ± 5 nm.
3. Turn the pump laser on in accordance with the pump laser operator's manual. Allow the pump beam to strike the titanium:sapphire crystal so condensation will not form.
4. Set the pump laser's output power level in accordance with the pump laser operator's manual.
5. If the Mira Optima controller is turned off, turn on the controller and set the CW/ML/β-Lock select switch to continuous wave (CW). Toggle the AUTO RANGE/PEAK RESET switch to the PEAK RESET position.

   If the Mira Optima controller is turned on, ensure the CW/ML/β-Lock select switch is set to CW. Toggle the AUTO RANGE/PEAK RESET switch to the PEAK RESET position.

[2] If the system does not lase, wait at least 15 minutes before adjusting any knobs (with the exception of opening the slit). Optimize the output power by adjusting the following controls in the order listed.

- The horizontal control and the vertical control for fine adjustment of the P1/P2 assembly. These two knobs are located at the very end of the Mira Optima laser head.
- M7 vertical and horizontal tilt angle controls.

Coherent recommends that the cavity be purged with dry N_2 when operating above 870 nm. Between 920 nm and 970 nm, a high velocity purge for several hours to reduce the cavity humidity to near zero may be required. A dry N_2 purge may also be required when operating at 761 ± 5 nm and at 820 ± 5 nm.

The numbered paragraphs below are keyed to, and supplement the flow chart on Figure 4-1.

[3] Optimize the slit width as follows:

1. Set the CW/ML/β-Lock switch to CW.
2. Open the slit by turning the slit width control clockwise several turns after the output power is maximized.
3. Optional check: Connect the fast diode output from the input bezel of the Mira Optima to an oscilloscope. The fast diode output must go through a 50-ohm load before going into the oscilloscope. Set the oscilloscope to 10 mV per division and a time base of 20 ns. Trigger off the fast diode input. The signal on the oscilloscope should similar to Figure 4-2.
4. Maximize output power by adjusting the following controls in the following order:
   - The horizontal control and the vertical control for fine adjustment of the P1/P2 assembly. These two knobs are located at the very end of the Mira Optima laser head.
   - M7 vertical and horizontal tilt angle controls.
   - Verify the Birefringent filter (BRF) micrometer is set to the desired wavelength in accordance with the tuning chart (wavelength vs. micrometer setting) furnished with the system. If the system stops lasing as the wavelength is changed, make the necessary adjustment to BP2 before continuing by following step 5. Otherwise, skip to step 6.
5. Turn BP2 control clockwise until laser power drops to 50% of its original power. Then turn the control counterclockwise:
   - 2 turns if the BRF is set for a wavelength longer than 960 nm.
   - 3 turns if the BRF is set for a wavelength between 730-960 nm.
   - 4 turns if the BRF is set for a wavelength shorter than 730 nm.
6. Reduce the slit width by turning the slit width control counterclockwise until the output power is reduced approximately 50%.
7. Center the slit on the beam by adjusting the slit translation control for maximum output power.
8. Repeat steps 6 and 7 several times to ensure the slit is centered on the beam.
9. Set the controller CW/ML/β-Lock select switch to ML.
10. Optimize the slit to obtain a maximum stable power level with zero CW content as viewed on the controller display.
11. Optimize BP2 to achieve the desired pulse width and a stable mode-locked pulsetrain.
12. Repeat steps 10 and 11 as necessary.
13. Optional check: Connect the fast diode output from the input bezel of the Mira Optima to an oscilloscope. The fast diode output must go through a 50-ohm load before going into the oscilloscope.
    - Slowly adjust the slit width until the display on the oscilloscope looks similar to Figure 4-3. Pulse spacing must be approximately 13 ns as shown.
    - Reduce sweep speed to 0.1 microseconds. If the display on the oscilloscope looks similar to Figure 4-4, the slit is too narrow. Open the slit until the pulse envelope shows no modulation.

The numbered paragraphs below are keyed to, and supplement the flow chart on Figure 4-1.

[4] Optimize the output as follows:

1. Connect the fast diode output from the input bezel of the Mira Optima to an oscilloscope. The fast diode output must go through a 50–ohm load before going into the oscilloscope.
2. Set the oscilloscope to 10 mV per division and a time base of 20 ns. Trigger off the fast diode input. The signal on the oscilloscope should look similar to Figure 4-2 or Figure 4-3.
3. Verify that the display on the oscilloscope looks similar to Figure 4-3.
4. If necessary, slowly adjust the slit width until the display on the oscilloscope looks similar to Figure 4-3.
5. Set sweep speed to 0.1 microseconds. If the display on the oscilloscope looks similar to Figure 4-4, the slit is too narrow. Open the slit until pulse envelope shows no modulation.
6. Adjust the BP2 and the slit until a stable pulse is achieved.

[5] Clean optics and optimize power as follows:

1. Clean all optics and input and output windows in accordance with the procedures in Chapter Six, Maintenance.
2. Optimize power (or fluorescence) using the following controls:
   - The horizontal control and the vertical control for fine adjustment of the P1/P2 assembly. These two knobs are located at the very end of the Mira Optima laser head.
   - M7 vertical and horizontal tilt angle controls.
   - Verify the BRF micrometer is set to the desired wavelength (or the peak of the gain curve) in accordance with the tuning chart (wavelength vs. micrometer setting) furnished with the system. If the system stops lasing as the wavelength is changed, make the necessary adjustment to BP2 before continuing.
3. Verify that the beam will pass through the BP1 and BP2 prism tips completely. If the beam is too close to either prism tip, translate the prism further into the beam.
   - For BP2, turn the control clockwise until laser power drops to 50% of original power, then turn the control counterclockwise 3 turns.

[6] Perform the following system checks:

1. Ensure cooling water to the crystal is turned on and the flow rate pressure and temperature are correct.
2. Verify the output power from the pump laser is correct.
3. Verify the output mode structure of the pump laser is correct.

The numbered paragraphs below are keyed to, and supplement the flow chart on Figure 4-1.

[7] Perform the following system checks:

1. Verify that the laser is operating in the main cavity, not in the auxiliary cavity.
2. Verify the BRF micrometer is set to the desired wavelength (or the peak of the gain curve) in accordance with the tuning chart (wavelength vs. micrometer setting) furnished with the system. If the system stops lasing as the wavelength is changed, make the necessary adjustment to BP2 before continuing. For troubleshooting purposes, try mode-locking at a wavelength near the peak of the gain curve.
3. Verify that the beam is completely passing through the BP1 and BP2 prism tips. If the beam is too close to either prism tip, translate the prism further into the beam. For BP2, turn the control clockwise until laser power drops to 50% of original power, then turn the control counterclockwise 3 turns.
4. If operating at 761 ± 5 nm, 820 ± 5 nm, or above 870 nm, verify that the cavity has been purged. In particular, if operating between 920 nm and 965 nm, the system must be purged for several hours with high-volume dry nitrogen, and remain sealed.
5. Verify that the starter galvo is operational. The starter should oscillate when the controller CW/ML/β-Lock select switch is set to ML and the slit is opened.
6. Verify that BP1 and BP2 are set at the minimum angle of deviation for the intercavity beam. See Prism Alignment Procedure in Chapter Six, Maintenance.
7. Ensure the cooling water to the crystal is turned on and the flow rate pressure and temperature are correct.
8. Verify that the output power from the pump laser is correct.
9. Verify that the output mode structure of the pump laser is correct.
10. Set the CW/ML/β-Lock switch to ML and check the system for mode-locking as follows:
    - Connect the fast diode output from the input bezel of the Mira Optima to an oscilloscope. The fast diode output must go through a 50-ohm load before going into the oscilloscope.
    - Set the oscilloscope to 10 mV per division and a time base of 20 ns. Trigger off the fast diode input. The signal on the oscilloscope may look similar to Figure 4-2.
    - If necessary, slowly adjust the slit width until the display on the oscilloscope looks like Figure 4-3. Pulse spacing must be approximately 13 ns as shown. Also refer to "Slit Width" in Chapter Seven, Theory of Operation.
    - Set sweep speed to 0.1 microseconds. If the display on the oscilloscope looks similar to Figure 4-4, the slit is too narrow. Open slit until pulse envelope shows no modulation.

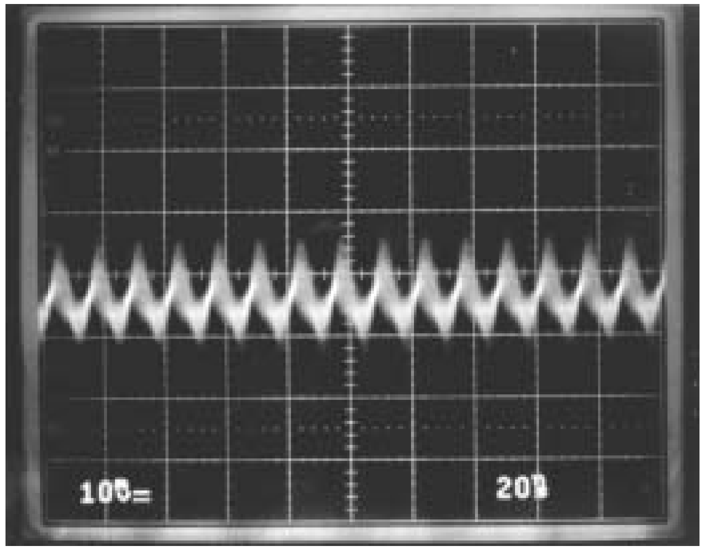


Figure 4-2. CW Signal Slit Open

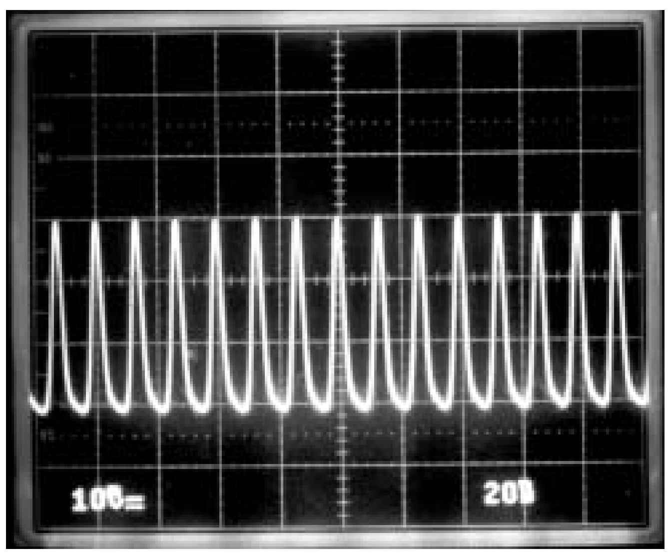
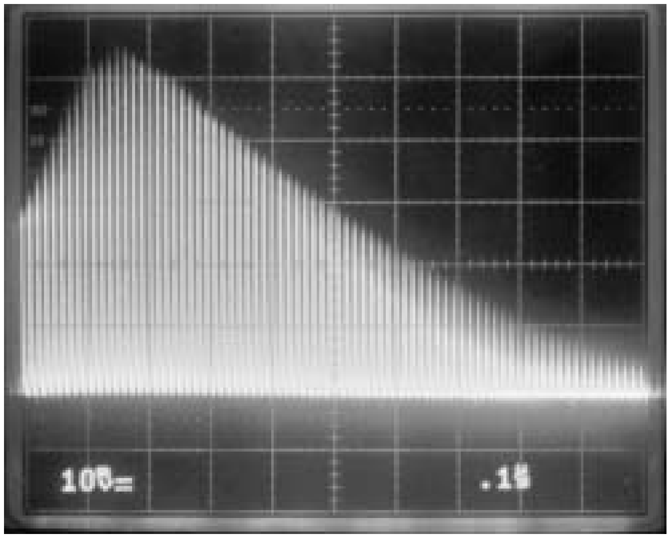
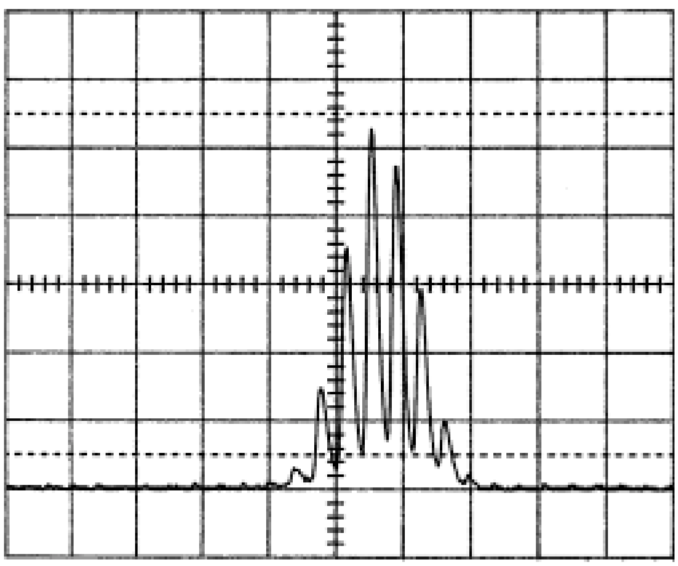


Figure 4-3. Mode-locked Signal Slit Optimized



A. OSCILLOSCOPE DISPLAY



AUTOCORRELATOR DISPLAY

Figure 4-4. Modulation of Pulse Envelope — Slit Too Narrow

Long-Term Shutdown

Long-term shutdown involves turning all equipment off. This procedure is intended for an extended period (i.e. longer than eight hours) of inactivity. Follow the short-term shutdown procedures for shorter periods of inactivity when a complete shutdown is unnecessary.

1. Close the pump shutter or block the pump laser beam.
2. Turn the pump laser off in accordance with the pump laser operator's manual.
3. Turn the cooling water flow to the titanium:sapphire crystal off.
4. Turn the nitrogen to the Mira Optima off or reduce the flow to a low rate.
5. Set the CW/ML/β-Lock select switch on the Mira Optima controller to CW (or turn the Mira Optima controller off).

Short-Term Shutdown

The following procedure is intended for short-term use (fewer than eight hours of inactivity). Follow the long-term shutdown procedures for longer periods of inactivity.

1. Close the pump shutter or block the pump laser beam.
2. Turn the cooling water flow to the titanium:sapphire crystal off. This eliminates condensation.
3. Set the CW/ML/β-Lock select switch on the Mira Optima controller to CW.

Short-Term Startup

The following procedure is intended for use only after a short-term shutdown; i.e., the laser has been inactive for fewer than eight consecutive hours.

1. Turn the water to titanium:sapphire crystal on.
2. Open the pump laser shutter or unblock the pump beam.
3. Set the CW/ML/β-Lock select switch on the Mira Optima controller to ML. If any problems are encountered during startup, perform a turn-on in accordance with Figure 4-1.

Using Power Display to Align Laser

The internal power meter and display are designed to facilitate and expedite the alignment of the laser cavity. If any mirror is sufficiently misaligned, the system will not lase. However, the fluorescence caused by the pump is detectable, and when the mirrors are close to being aligned, this fluorescence is enhanced. Therefore, adjusting mirrors to increase the fluorescence level will eventually bring them into alignment sufficiently to allow lasing action. The fluorescence level is many orders of magnitude lower than the lasing level and hence the power meter must have many orders of magnitude of dynamic range in order to correctly measure both lasing levels and fluorescence.

A special feature of this meter is that it will automatically change range as the power is increased. However, it will not auto-range downward. This prevents annoying range changes when the power is erratic—as it is when the mirrors are close to alignment. In order to auto-range downward, in the event that the power decreases and cannot be recovered easily, the AUTO RANGE switch should be momentarily actuated.

Each time the power has increased sufficiently to require a range switch, an audible beep will sound. Therefore, every time a beep is heard, a new high power has been achieved—higher than the previous one—indicating a steady progression of mirror adjustments toward the optimal alignment. In between each beep, the power bar display and vernier increase in length continually, as each new range is reached.

Before lasing occurs, it is necessary to detect very small increases in the fluorescence level in order to determine the correct adjustment direction. To this end, the sensitivity of the display can be enhanced by introducing negative offset followed by a gain increase. Most of the steady signal is suppressed, leaving only variations visible. This feature is referred to as "DC Suppression". The DC Suppression feature is activated automatically by pressing and holding AUTO RANGE for at least 2 seconds.

Furthermore, only when the words "DC SUP" appears in the lower left-hand corner of the display can this feature be activated. This symbol appears only when the output is very low as when the system is not lasing. Once lasing, DC SUP is deactivated. This assures that "0" on the meter is truly zero to the limit of resolution of the meter.

In summary, if lasing is lost, the following sequence of actions set up the meter for laser alignment.

1. Depress AUTO RANGE briefly.
2. Depress AUTO RANGE for at least 2 seconds until the words DC Suppress appear on the display.

The power display is now set to its maximum sensitivity for alignment.

Other Features of the Display

Peak Marker

The peak marker (Figure 3-13, item 2) indicates the peak power reached since the last peak reset. The peak marker will remain in the same position if the display briefly auto-ranges down in intensity. The PEAK RESET switch resets the peak marker to the present power. It also resets the vernier to zero.

Vernier

The vernier display (Figure 3-13, item 6) magnifies any changes in power from a reference level established at the most recent Peak Reset. It is used for monitoring power increases or decreases from a reference level while adjusting alignment, slit width, etc. It is re-set to zero when a peak reset is requested.

Digital Power Indicator

The digital power indicator is proportional to average power out for a fixed wavelength. It can be used as a logging device to record and compare powers. Absolute power is measured by using an externally calibrated power meter, which is available as an accessory (see "Mira Optima Options, Accessories, and Systems", Appendix B).

When in the DC SUP mode, (i.e., the system is not lasing) this number is not proportional to power, but increases when fluorescence increases, indicating trends.

RH

RH indicates the relative humidity in the laser cavity at the position of the head board. This measurement can be used to ensure that condensation does not form anywhere on the laser head. See the paragraph titled "Dry Nitrogen Purge" in Section Five, Installation and Alignment, for more information.

Error Messages

Power display error messages are shown in Table 4-1.

Table 4-1. Power Display Error Messages

ERROR MESSAGE AND MEANING	ACTION REQUIRED
Power Low-return switch to CW The control box was turned on with the switch in CW. The position of the switch was subsequently changed and the laser was not lasing. *(Will be displayed until switch is returned to the CW position)*	Return controller to the CW position and re-establish lasing.
Power low-use CW mode The laser is not lasing and the switch position is in the ML or β-Lock position. The computer cannot determine the system configuration. *(Will be displayed until switch is returned to the CW position)*	Return controller to the CW position and re-establish lasing.
DC Suppressing Out of Range This indicates a failure of the fluorescence power meter, most likely due to component malfunction in the controller or head board. The processor has tried all possible gain settings and the DC Suppression DAC values before issuing this message. The fluorescence power meter information will be invalid but other functions may be intact. *(Will be displayed for one second, then operation continues)*	Check the following: • Head board alignment • All connections
Stage 1 Saturation Error The output of the first-stage amplifier of the power meter exceeds 1.6 V at the minimum possible gain setting. The power meter information will be invalid, but other system functions may be intact. *(Will be displayed for one second; then operation continues)*	Check the following: • Alignment of the head board • Attenuate the beam entering the photocell
Error: Power gain optimization failed The power meter signal is changing too rapidly. *(Will be displayed as long as symptom persists)*	Check the following: • Pump laser output power meets specifications • Mira Optima output power meets specifications • Verify BRF is on correct tuning order • Optimize slit

OPERATOR'S MANUAL

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CHAPTER FIVE
INSTALLATION AND ALIGNMENT

Introduction

Installation and alignment procedures contained in this chapter are intended for use during initial installation, or if the pump laser or Mira Optima laser head has been moved. Re-alignment after an optics change is contained in the applicable chapter. Refer to Chapter Three, “Controls and Indicators”, as required for the location of all the controls used in this chapter.

Coherent recommends that the pump laser for the Mira Optima be the Coherent Verdi Series DPSS lasers (V5, V6, V8, and V10). The pump laser must meet all specifications before starting Mira Optima alignment. Refer to the pump laser operator’s manual as required for pump laser operation, alignment, turn-on and shutdown procedures, and safety information. Refer to Appendix A if the pump laser is from a Coherent Ion source.

Changing the voltage selector card must be done by trained personnel. This task is accomplished during installation by a Coherent service engineer.

Turn the system off and disconnect the unit from facility power. Wait at least 15 seconds before changing the voltage selector.

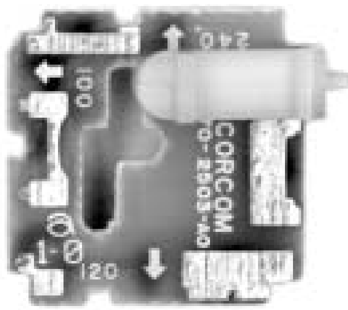
Voltage Selection

If required, change the voltage selector as follows:

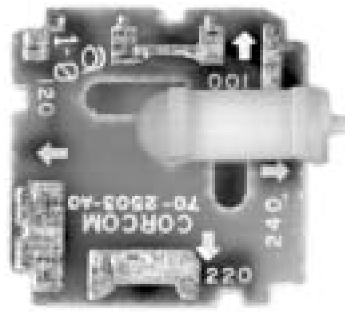
1. Remove the power cord from the facility outlet.
2. Remove the power cord from the controller rear panel.
3. Remove the voltage selector assembly using a small flat blade screwdriver.
4. Remove and set aside the cover/fuse block assembly.
5. Using a hemostat or needle-nose pliers, remove the voltage selector.
6. Adjust the position of the pointer for the appropriate voltage as shown on Figure 5-7.

Note that the pointer must line up in the slot on the voltage selector assembly for the desired voltage. Also note that the

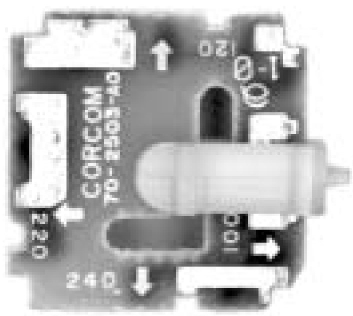
arrow on the voltage selector and the number indicating the desired voltage will point towards the interface box when installing the voltage selector. A pointer on the voltage selector must mate with a pointer on the voltage selector assembly during re-installation.



A) 100 VOLTS



B) 120 VOLTS



C) 220 VOLTS

D) 240 VOLTS

Figure 5-1. Voltage Selector Card Orientation

Cooling Water

The Mira Optima titanium:sapphire crystal requires a consistent flow of cooling water for proper operation. Best performance will be achieved using a separate closed-loop water conditioner that maintains the water temperature to the crystal within ± 0.1°C. Other water parameters include:

Minimum Flow Rate	0.08 gal/min or 0.3 liters/min
Maximum Pressure	30 psi or 207 kPa
Maximum Temperature	20°C

Dry Nitrogen Purge

In order for the Mira Optima to mode-lock properly at certain wavelengths, optical loss due to atmospheric absorption must be minimized by maintaining a dry nitrogen purge of the cavity. The dry nitrogen purge also keeps the relative humidity to below 5%. This is recommended in general for operation above 870nm. Specific regions where the nitrogen purge may be necessary include:

- 760 ± 10 nm
- 780 ± 5 nm
- 825 ± 10 nm
- 890 ± 10 nm
- 910 nm to 980 nm

A high-velocity purge in duration from less than one hour to several hours may be needed to reduce the relative humidity, which can be read on the controller display, to below 5%. Recommended flow rates are listed below.

Initial Purge	10 CFH (ft^3/hr) or 4.7 liters/min
Later purges	2 CFH (ft^3/hr) or 0.94 liters/min

Equipment Used During Installation and Alignment

- Power meter, Coherent Fieldmaster or equivalent (0 to 10 Watts)
- Laser safety glasses to protect against the wavelength exiting the laser head and to protect against the pump beam wavelength
- Mira Optima accessory kit (supplied with the laser)
- IR viewer (recommended)
- Autocorrelator and/or spectrometer (recommended)
- 350-MHz oscilloscope (recommended) or an oscilloscope with a fast enough sweep to cleanly resolve the 76-MHz train of pulses from the Mira Optima fast photodiode

Installation and Alignment Summary

A summary of the Mira Optima installation is listed below. The following paragraphs in this chapter contain detailed procedures for each item listed.

1. Install the pump laser in accordance with the pump laser operator’s manual.

2. Ensure that the pump beam is at the correct height for Mira Optima pumping and level to the optical table. (The standard riser for the Verdi pump laser satisfies these requirements).
3. Evaluate the pump laser output beam quality.
4. Install the Mira Optima using the Abbreviated Alignment Procedure found in this chapter.
    a.) Position the Mira Optima so the pump beam enters the cavity as described in the Abbreviated Alignment procedure.
    b.) Adjust the auxiliary, or CW, cavity to achieve CW lasing.
    c.) Diffract a portion of the beam from the auxiliary cavity to help align and achieve CW lasing in the main (or prism) cavity.
    d.) Optimize the continuous wave (CW) output.
    e.) Mode-lock the Mira.
    f.) Optimize the pulsewidth.
5. If lasing cannot be achieved using the abbreviated alignment procedure, then perform the Full Alignment Procedure located later in this chapter.

The abbreviated alignment procedure is appropriate when the laser was operating properly when previously shut down, and that this cavity mirror alignment is still intact. If no mirrors have been removed or adjustment knob positions altered, the abbreviated alignment is usually all that will be required, even after shipment. The full alignment procedure is appropriate when the previous cavity mirror alignment has been lost and thus the adjustment (or verification) of each cavity mirror is necessary.

The abbreviated alignment procedure can also be used if the pump laser has been moved or replaced. In this case, the pump laser is repositioned to satisfy the initial alignment criteria rather that repositioning the Mira Optima. The criteria are that the pump beam at low power is simultaneously centered on:

- Pump optic P4; it helps to be centered on pump optic P0 for straight-in pumping or P1 for left side or right side pumping
- Pump lens L1
- Auxiliary cavity optic M9
- The Titanium:sapphire crystal

Abbreviated Alignment Procedure

This procedure must be followed during initial installation, or if the Mira Optima or pump laser (or both) have been moved. If proper operating results are not obtained, perform the Full Alignment Procedure located in this chapter.

Safety glasses must be worn when performing this alignment as stray beams could be present.

Installation Notes

- The pump input end of the Mira Optima is opposite its output end. There are three pump input windows on this end that give the flexibility of pumping the Mira Optima from the left side, right side, or straight into the end.
- Correct results may not be obtained if the pump laser is other than a Coherent Verdi Series DPSS lasers (V5, V6, V8, and V10) or Coherent Innova Ion laser series (200, 300, 400, or Sabre) pump laser.
- If dirt or other foreign material on an optic is visible during the installation and alignment procedure, clean the optic in accordance with the cleaning procedures located in Chapter Six, Maintenance.

Coherent recommends that one beam steering mirror *at most* be used externally to the Mira Optima. Long distances must not exist between the pump laser and Mira Optima laser.

If beam steering optics are used, the optics must have a dielectric coating suitable for the pump laser output. If the optic has the wrong coating, this could result in pump beam power loss, angular instability, mode degradation and altered pump beam divergence that will impair performance of the Mira Optima.

Coherent also recommends that beam tubes be installed between the pump laser and Mira Optima laser for safety and stability to air currents. Exposed high-power beam paths can pose a laser safety hazard, and air currents can have a significant beam steering effect.

Configuring Mira Optima for Left-Side, Right-Side, or Straight-In Pumping

The pump laser can be installed for left-side, right-side, or straight-in pumping (Figure 5-1). In the case that the pump optic P0 mount is to be installed at this stage or the pump optic P1 mount is moved to configure Mira Optima for a different pump configuration, perform the Coarse Pump Alignment procedures below. Final adjustment for P1 is located in the Mira Optima Installation procedure located later in this chapter.

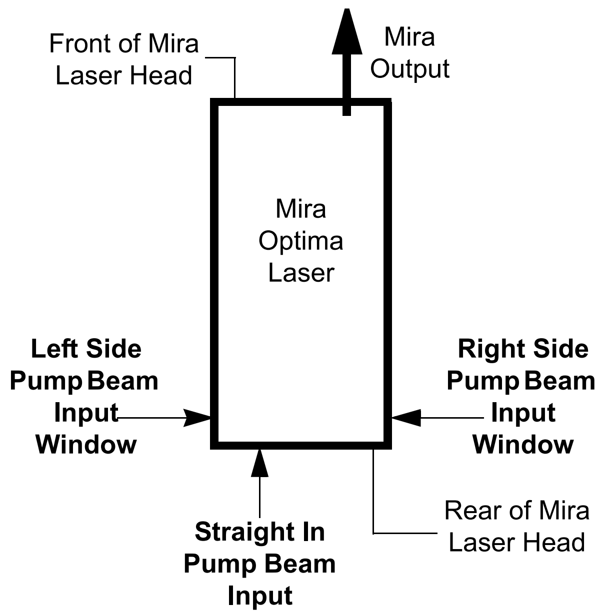


Figure 5-2. Directions for Straight-In, Left-Side and Right-Side Pumping

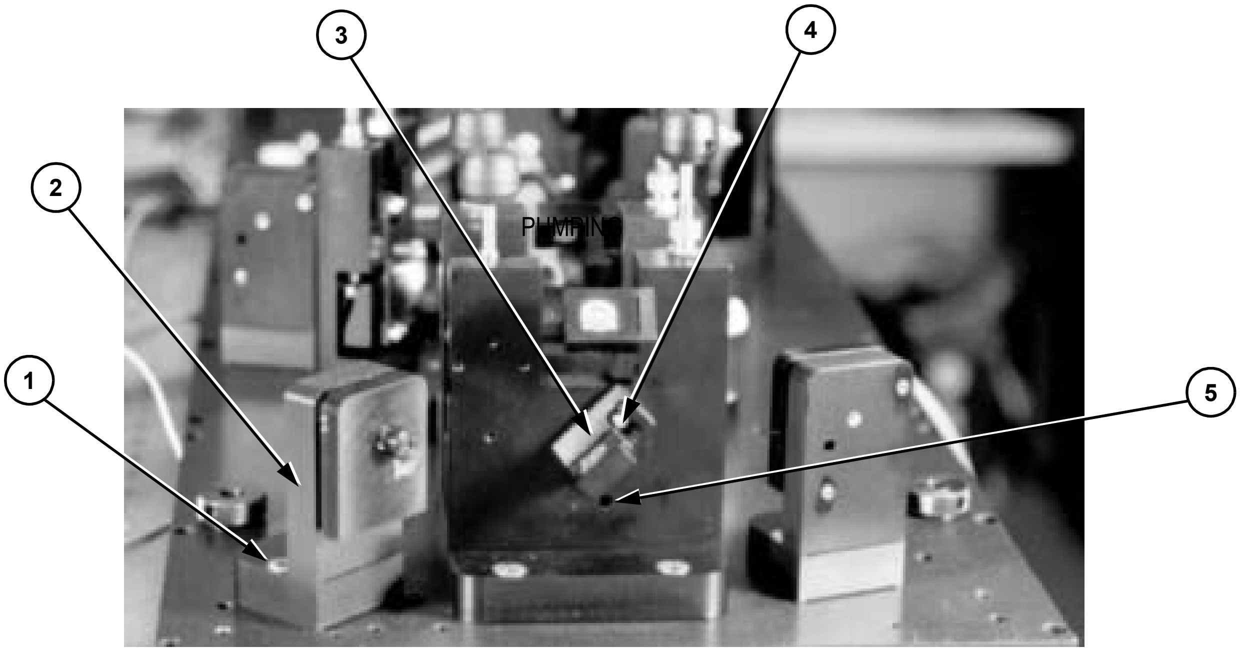
Coarse Pump Alignment procedure

Straight-In Pumping

For straight-in pumping, the P0 pump optic assembly is installed in the location shown on Figure 5-3. Pump optic P1 and the P1 mount screw must also be located in the position shown on Figure 5-3. If the Mira Optima is received configured for straight-in pumping and the laser will be used in that configuration, do not adjust P0 or P1. Proceed to the procedure for pump laser setup.

If the P0 mount requires installation, perform the following installation procedures.

1. Block the pump laser beam.



1. P0 mount retaining screws
2. P0 optic assembly
3. P1 assembly
4. P1 mount retaining screw for left-side (and straight-in) pumping
5. P1 mount hole for right side pumping

Figure 5-3. Mira Optima Pump Configurations

2. Place the P0 mount on the baseplate and loosely install only the one mount retaining screw indicated in Figure 5-3.
3. Position the P0 mount so the optic face is perpendicular to the incoming beam.
4. Ensure the pump laser is at low power (i.e., less than 100 mW). Open the pump laser shutter.
5. Adjust the P0 vertical tilt angle control so the pump laser beam retro-reflection is at the same vertical height as the incoming beam. (The pump beam is assumed to have been leveled before performing this step.)
6. Block the pump laser beam. Rotate the P0 mount and install the second mounting screw. Tighten both P0 retaining mounting screws.
7. Adjust the P0 horizontal tilt angle control to center the pump beam horizontally on P1. P1 may require repositioning as described below before this step can be completed. Readjustment of the vertical control should not be necessary at this time.

If the mounting screw for pump optic assembly P1 must be moved to achieve straight-in pumping (i.e., if the laser was previously configured for right-side pumping), perform the following procedure to roughly align the P1 mount. Final P1 adjustment instructions are located in the Mira Optima installation procedures.

1. Block the pump laser beam.
2. Remove the retaining screw from the right side position indicated by arrow 5 on Figure 5-3.
3. Position the P1 optic assembly at approximately 45 degrees from horizontal and reinstall the retaining screw in the left side, position indicated by arrow 4 on Figure 5-2.

Right Side Pumping

For right side pumping, the P0 pump optic assembly is not used and it does not matter whether it is installed or not. The P1 mount retaining screw must be in the position indicated by arrow 5 on Figure 5-3. If the Mira Optima is received configured for right side pumping and the laser will be used in that configuration, do not adjust P0 or P1. Proceed to the procedure for pump laser setup.

If the mounting screw for pump optic assembly P1 must be moved to achieve right side pumping, perform the following procedure to roughly align the P1 mount. Final P1 adjustments are located in the Mira Optima installation procedures.

1. Block the pump laser beam.
2. Remove the retaining screw from the position indicated by arrow 4 on Figure 5-3.
3. Position the P1 optic assembly at approximately 45 degrees with respect to vertical and reinstall the retaining screw in the position indicated by arrow 5 on Figure 5-3.

Left Side Pumping

For left side pumping, the P0 pump optic assembly must be removed from the beam path if it is installed. The P1 mount retaining screw must be in the position indicated by arrow 4 on Figure 5-3. If the Mira Optima is received configured for left side pumping and the laser will be used in that configuration, do not adjust P1. Proceed to the procedure for pump laser setup.

If the mounting screw for pump optic assembly P1 must be moved to achieve left side pumping, perform the following procedure to roughly align the P1 mount. Final P1 adjustment instructions are

located in the Mira Optima installation procedures later in this chapter.

1. Block the pump laser beam.
2. Remove the P0 pump optic assembly (if installed) by removing two retaining screws (Figure 5-3, item 1).
3. Remove the retaining screw from the position indicated by item 5 on Figure 5-3.
4. Position the P1 optic assembly at approximately 45 degrees with respect to vertical and reinstall the retaining screw in the position indicated by item 4 on Figure 5-3.

Pump Laser Setup

1. Take into account the location and height of the Mira Optima output beam, the pumping configuration (right side, left side, straight in), and the physical dimensions of both the Mira Optima and the Verdi pump laser when planning their positions on the optical table in relation to other equipment. Refer to this operator's manual and the Verdi operator's manual for the appropriate dimensions.
2. The recommended distance from the Verdi pump laser to the Mira Optima is between 6 in. and 24 in. (15 cm and 60 cm). Using more than one steering mirror is not recommended.
3. Install the Verdi pump laser according to procedures outlined in the Verdi operator's manual. For safety, ensure that the Verdi pump laser is turned off when moving it into position on the optical table.
4. A Verdi pump laser correctly installed on its riser block will have an output beam that is both the correct height for pumping the Mira Optima and level with the optical table on which it sits. It is helpful (but not necessary) to also orient the output beam of the Verdi so that it travels parallel to a side of the optical table.
5. If a turning mirror is used, use the top hole in the alignment apertures to ensure that the beam remains level with the table. These apertures can also be bolted temporarily to holes along a row in the table to orient the pump beam along a desired line. Roughly aligning the Mira Optima parallel to the optical table is a good preliminary orientation for installing the Mira Optima.
6. Once the Verdi pump laser is positioned in approximately the correct position, operate the Verdi at as low a power as is practical when making small adjustments (i.e., less than 0.1 W).

The Verdi can be turned down to as low as 0.01 W in output power. Controls on the front panel of the Verdi controller will allow convenient toggling between high-pump power for normal operation and low-pump power for alignment. Refer to the Verdi operator's manual for instructions about how to set these controls.

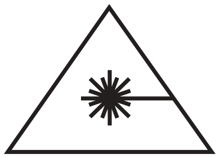
Mira Optima Installation

1. Block the Verdi pump laser beam and remove any power meter or alignment fixtures from the pump beam path.
2. Open the Mira Optima head covers.
3. Position the Mira Optima in the pump beam path approximately 6 in. to 24 in. (15 cm to 60 cm) from the Verdi pump laser allowing enough room for a power meter. A helpful starting point is to position one side of the Mira Optima roughly parallel to the beam from the Verdi pump laser.
4. Ensure the Verdi pump laser is set to low power (less than 100 mW). Open the pump beam shutter.
5. Position the Mira Optima so the pump laser beam enters the Mira Optima and strikes the center of P0 (or strikes the center of P1 for left-side or right-side pumping). The rear feet of the Mira Optima are adjusted at the factory and must remain at the factory setting. Do not adjust the feet to center the pump beam on P0 (or P1).
6. Turn the BP1 micrometer clockwise (towards the lower reading) until it stops. This translates the prism out of the beam path and the beam is directed into the CW alignment cavity. Refer to the optical schematic, Figure 2-2.
7. If the P1 mirror mount has not been moved (no pump configuration change), proceed to the next step.

   If the P1 mirror mount *has* been moved, then the factory alignment of P1 has been lost. Perform both of the following procedures to center the beam on P4, the remaining pump chain optics, and the intracavity optics noted in below.

   a.) Gently rotate the front end of the Mira Optima and/or make small translations along its long axis.

   b.) Slightly loosen the P1 mount retaining screw. Make the necessary adjustments to center the beam on the optics. Tighten the P1 retaining screw.

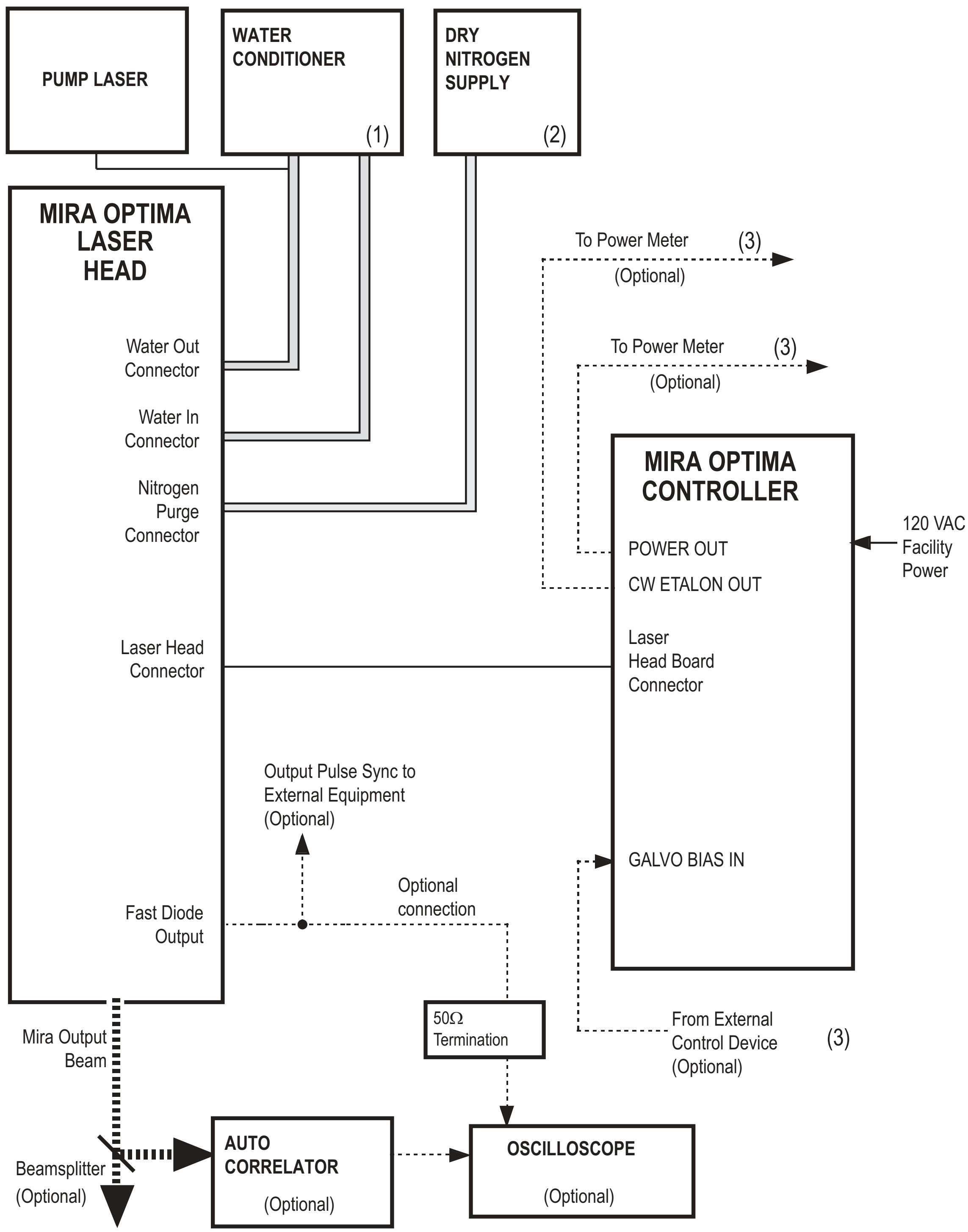


Be extremely careful that P1 does not go so far out of nominal alignment that the beam misses P2. This can cause a potential eye hazard.

8. Locate the portion of the pump beam reflected from M5 to M8 and onward to M9. If this is being performed as part of an installation or if the Mira Optima and pump laser have been moved, rotate the Mira Optima on the table and make small adjustments to the P2 fine adjustment pump controls until the pump beam is exactly centered on M9. Otherwise, the positioning of the pump beam on M9 will be addressed elsewhere.
9. Verify the that the following conditions are accurate:
   a.) The pump beam is centered on P1 (P0, in the case of straight-in pumping)
   b.) The pump beam is centered on P4
   c.) The pump beam is approximately centered on L1
   d.) The pump beam is travelling down the approximate center of the Ti:Sapphire crystal, well clear of the edge of either face. To see this, carefully slide back the beam shields on the crystal. Return the beam shields to the original position.

Note: The crystal can be damaged if the high-power pump beam strikes the edge of the crystal.

10. Secure the two rear Mira Optima feet, which are under the pump input end, with the clamps provided.
11. Clamp the front foot.
12. Verify the that the following conditions are accurate:
    a.) The pump beam is still centered on P1 (and P4, if the P1 mirror mount was adjusted).
    b.) The pump beam is approximately centered on L1.
    c.) The pump beam is vertically centered on M9.
13. Connect the controller to the Mira Optima laser head as shown in Figure 5-4 and turn on the controller.
14. Block the Mira Optima output aperture with a power meter or beam block. Adjust the pump laser to normal operating level (high power).



(1) Refer to paragraph titled "Cooling Water" in this chapter for specifications.
(2) Refer to paragraph titled "Dry Nitrogen Purge" in this chapter for specifications.
(3) Refer to Table 3-12 for a description of the GALVO BIAS IN, POWER OUT, and the CW ETALON OUT signals.

Figure 5-4. Mira Optima Interconnection Diagram

15. Verify that the birefringent filter (BRF) is at the peak of the tuning curve. Refer to the tuning chart for the micrometer setting.
16. Open the slit by rotating the slit width control (Figure 3-4) clockwise until it stops.
17. Set the mode select switch to CW.
18. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds to activate the DC suppress function.
19. Make small adjustments to the P2 vertical and horizontal tilt controls to maximize power on the controller display. If the Mira Optima lases, skip the next step.
20. Make small adjustments to the following controls to maximize the power on the controller display. Adjust one control at a time and proceed in the order listed.

    a.) M9 vertical and horizontal tilt angle controls.

    b.) P2 vertical and horizontal tilt angle controls.

    Repeat this step until the Mira Optima is lasing. Maximize power using the above controls after lasing starts.
21. Once the cavity is lasing, maximize power (on the controller display) by adjusting the following controls:

    a.) M5 vertical and horizontal tilt angle

    b.) P2 vertical and horizontal tilt angle pump

    c.) M9 vertical and horizontal tilt angle

    d.) M0 vertical and horizontal tilt angle
22. To transition from the auxiliary cavity and set up the main cavity, including the prisms:

    a.) Turn the BP1 micrometer counterclockwise towards a higher micrometer reading to bring the BP1 into the beam path. To verify, place a white card in front of M9 and then translating BP1 until the pump beam is no longer visible on the card.

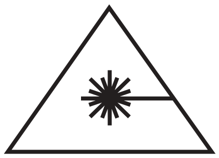
    b.) Once the pump beam disappears, turn the micrometer to the setting located on the test data sheet you received with the Mira Optima.
23. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds to activate the DC suppress function.

24. Use only the M7 vertical and horizontal tilt angle controls and the CW display to maximize the power output.

Mode-Locking

1. Set the CW/ML/β-Lock switch to CW.
2. Open the slit by turning the slit width control clockwise several turns after the output power is maximized.
3. Verify the BRF micrometer is set to the desired wavelength in accordance with the tuning chart (wavelength vs. micrometer setting) furnished with the system.
4. Verify that the system is aligned and at maximum CW power.
5. Turn the BP2 control clockwise until laser power drops to 50% of original power.
   a.) Turn the BP2 control counterclockwise 4 turns if the BRF is set for a wavelength shorter than 730 nm.
   b.) Turn the BP2 control counterclockwise 3 turns if the BRF is set for a wavelength between 730-960 nm.
   c.) Turn the BP2 control counterclockwise 2 turns if the BRF is set for a wavelength longer than 960 nm.
6. Reduce the slit width by turning the slit width control counterclockwise until the output power is reduced approximately 50%.
7. Center the slit on the beam by adjusting the slit translation control for maximum output power.
8. Repeat the previous two steps several times to ensure the slit is centered on the beam and the power is reduced by about 50%.
9. Set the controller CW/ML/β-Lock select switch to ML.
10. Optimize the slit to obtain a maximum stable power level with zero CW content as viewed on the controller display.
11. Adjust the BP2 micrometer for optimum pulsewidth. The pulsewidth is monitored with an autocorrelator.
12. The fast diode display from the Mira Optima laser head can be displayed on a 50-ohm-terminated oscilloscope to determine mode-locked operation (Figure 4-3).

Full-Alignment Procedure



Safety glasses must used when performing this alignment as stray beams could be present that pose significant safety hazards.

This procedure is intended for use when the abbreviated alignment procedure does not achieve the correct results, or when directed to do so elsewhere in this operator's manual. If the Mira Optima is not operating correctly, refer to Figure 4-1.

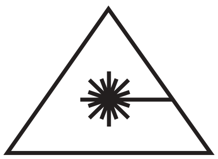
Mira Optima Installation

1. Once the pump laser orientation has been established and the mode quality has been checked, block the pump laser beam and remove any power meter or alignment fixtures from the pump beam path.
2. Open the Mira Optima head covers.
3. Position the Mira Optima in the pump beam path approximately 6 to 24 in. (15 to 60 cm) from the pump laser, allowing enough room for a power meter.
4. Ensure the pump laser is set to low power (less than 100 mW). Turn the cooling water to the Mira Optima on and open the pump beam shutter.
5. Position the Mira Optima so that the pump laser beam enters the Mira Optima and strikes the center of P0 (or P1). The rear feet of the Mira Optima are adjusted at the factory. **Do not adjust the feet height to center the pump beam on P0 (or P1).**
6. Turn the BP1 micrometer clockwise until it stops. This translates the prism out of the beam path. Refer to the optical schematic in Figure 2-2.
7. If the P1 mirror mount has not been moved (no pump configuration change), skip this step and proceed to the next step.

   If the P1 mirror mount has been moved, then the factory alignment of P1 has been lost. Perform both of the following instructions to center the beam on P4 and the remaining pump chain optics.

   a.) Gently rotate the front end of the Mira Optima and/or make small translations along its long axis.

b.) Slightly loosen the P1 mount retaining screw. Make the necessary adjustments to center the beam on the optics. Tighten the P1 retaining screw.



Be extremely careful that P1 does not go so far out of nominal alignment that the beam misses P2. This can cause a potential eye hazard.

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8. Gently move the Mira Optima until the beam is centered on P4 horizontally.
9. Check that the beam is also still striking the center of P1. If this cannot be accomplished, make small adjustments to the P1 mount and to the position of the Mira Optima until this is achieved.
10. Verify that the following conditions are correct:

    a.) The beam is still centered on P0 (straight-in pumping), P1, and P4

    b.) The beam is approximately centered on L1
11. Gently slide back the beam shields on the crystal and verify that the pump beam is travelling down the approximate center of the crystal, well clear of the edge of either face.

Note: The crystal can be damaged if the high-power pump beam strikes the edge of the crystal.

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12. Return the beam tubes to their original position.
13. Secure the two rear Mira Optima feet (input end) with the clamps provided.
14. Clamp the front foot.
15. Verify that the following conditions are accurate:

    a.) The beam is still centered on P0 (straight-in pumping), P1, and P4

    b.) The beam is approximately centered on L1

    c.) The beam is still centered on the crystal

    d.) The beam is still vertically centered on M9
16. Connect the controller to the Mira Optima laser head as shown in Figure 5-4 and turn on the controller.

17. Set the mode select switch to CW and toggle the AUTO RANGE/PEAK RESET switch to PEAK RESET.
18. Block the Mira Optima output aperture with a power meter or beam block.
19. Adjust the pump laser to normal operating level (high power).
20. Verify that the BRF is at the peak of the tuning curve. Refer to the tuning chart for the micrometer setting.
21. Open the slit by rotating the slit width control (Figure 3-4) clockwise until it stops.
22. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds to activate the DC suppress function.

Auxiliary Cavity Alignment

1. Tune to a wavelength near the peak of the gain curve.
2. Turn the BP1 micrometer clockwise (toward lower micrometer readings) until it stops. This translates the prism out of the beam path. Refer to the optical schematic on Figure 2-2.
3. Locate the pump beam reflection (in front of M8) from M5. Use the M5 vertical and horizontal tilt angle controls to position the beam on M8. Center the beam in the vertical plane and just to the right of center in the horizontal plane (see Figure 5-5). With this alignment, the cavity beam will strike the center of the optic.

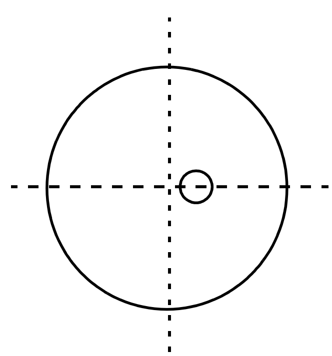

Figure 5-5. Pump Beam Spot on M8

4. Turn the BP1 micrometer counterclockwise (toward higher micrometer readings) until the prism fully intercepts the pump beam. The pump beam spot now will appear to the left of M6.

5. Use the M5 vertical tilt angle controls to align the center of the spot vertically with center of the M6 optic as shown on Figure 5-6 (refer to Appendix A for an alternate figure if the pump source is a Coherent Ion laser). The lower hole on the alignment fixture can be used to set the height.

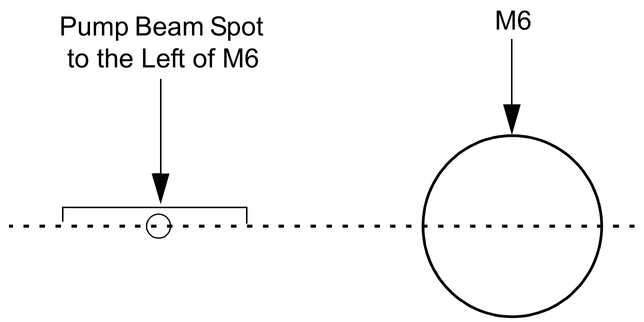

Figure 5-6. Vertical Alignment of Pump Beam

6. Turn the BP1 micrometer clockwise (toward lower micrometer readings) until it stops. The pump beam spot should appear on M8 as shown on Figure 5-4, except the vertical position may have changed. Do not readjust M5.

7. Use the M8 vertical and horizontal tilt angle controls to position the pump beam on M9. Center the beam in the vertical plane and just to the left of center in the horizontal plane (see Figure 5-7). With this alignment, the cavity beam will strike the center of the optic.

8. Locate the pump beam retro-reflection from M9 as follows:

   a.) Adjust the pump laser to high power.

   b.) Use a 3/32 in. Allen head wrench to adjust the M9 vertical tilt angle control back and forth to locate the M9 retro-reflection on M8.

   c.) The correct retro-reflection is the brightest of the reflections.

   d.) Adjust the M9 vertical and horizontal tilt angle controls to position the pump retro-reflection on top of the pump beam spot coming from M5 and striking M8.

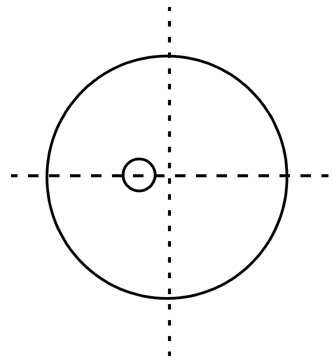

Figure 5-7. Pump Beam Spot on M9

9. Close and center the apertures on M2 and M3.
10. Locate the outline of the butterfly starter optic projected on the M3 aperture. Use the M4 vertical tilt angle controls to vertically position the brightest center spot of the fluorescence through the center of the butterfly outline. Place a white card in front of M3 to help see this outline.
11. Adjust the height of the M2 aperture to align with the center of the shadow created by the starter.
12. Use the M4 horizontal tilt angle controls to position the fluorescence in the M3 alignment aperture horizontally.
13. Open the M3 alignment aperture.
14. Use the M3 vertical and horizontal tilt angle controls to center the fluorescence on the M2 alignment aperture.
15. Remove the slit assembly by loosening the two screws at the base using a 5/64-in. Allen head driver.
16. Use the M2 vertical and horizontal tilt angle controls to position the fluorescence on to the center of the output coupler M1. The beam alignment tool has a recessed space so it can be placed over the output coupler M1 without touching the mirror itself.
17. The edges of the tool will line up with the edges of the output coupler mount to center the lower hole on the output coupler. An accurate way to ensure the lasing spot is centered once lasing is achieved, Align the brightest part of the fluorescence into the lower hole in the alignment tool.
18. Locate the retro-reflection from M1 on the M2 aperture. An IR viewer will make the spot easier to locate.

19. Adjust the M1 vertical and horizontal tilt angle controls until the retro-reflection is centered in the aperture.
20. Open the M2 aperture.
21. Place a white card after M1. Two fluorescence spots should appear on the card. The dimmer of the two spots is the retroreflection from M9. Make small adjustments to the M9 vertical and horizontal tilt angle controls to position the dimmer retro-reflection over the brighter spot.
22. If the system is not lasing, make small adjustments to the following controls to maximize the intensity on the controller display. Adjust one control at a time and in the order listed.
    a.) M9 horizontal tilt angle and then vertical tilt angle controls.
    b.) Output coupler M1 horizontal and vertical tilt angle controls.

    Repeat this step and step 13 to step 14 until the Mira Optima is lasing.
23. Once the cavity is lasing, maximize the output power by adjusting the following:
    a.) Output coupler M1 vertical and horizontal tilt angle controls
    b.) M9 vertical and horizontal tilt angle controls
    c.) P2 vertical and horizontal tilt angle controls
24. Use an IR viewer to verify that the beam travels through the center of both butterfly arms vertically.
25. Use the M3 vertical tilt angle control to adjust (walk) the vertical position on the butterfly arm closest to the slit, if necessary. Use M4 vertical tilt angle control to adjust (walk) the vertical position on the butterfly arm closest to the laser cover side. Refer to the paragraph titled "Walking The Beam".
26. Use an IR viewer to verify that the beam travels through the center of the output coupler. If not, walk the beam using M2 and M1.
27. Reinstall the slit assembly.
28. Open the slit so that the beam clearly passes the slit edges.

Main Cavity Alignment

1. Tune to a wavelength near the center of the optics set tuning range.
2. Turn BP1 micrometer translation adjust (Figure 3-2) counter-clockwise to translate prism BP1 into the beam path, so the output power is reduced by 50%.

Do not rotate either BP1 or BP2. The rotational position of these prisms is critical for optimal tuning and pulsewidth. The procedure for setting the rotational position of the prisms is detailed later in the case that the rotational position of one of the prisms has been accidently moved from the factory setting.

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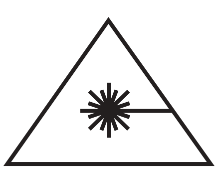
3. Locate the beam on the M6 optic that is refracted from the auxiliary cavity.
4. Close and adjust the M6 aperture to center it on the refracted beam spot (it may be necessary to block the retro-reflection from M7).
5. Follow the reflection from M6 to BP2. If necessary, translate BP2 until the tip of the prism refracts the beam to M7.
6. Locate the beam on the M7 optic that is refracted from BP2.
7. Adjust the M6 vertical tilt control until the beam at M7 is at the height of the alignment aperture.
8. Adjust the horizontal of M6 until the center wavelength of the optics set strikes within 1 mm of the center of the M7 optic.
9. Locate the retro-reflected spot (from M7) on the M6 aperture face. Take note of the power reading on the Optima control box.
10. Adjust M7 horizontal and vertical tilt angle controls to position the retro-reflection into the M6 alignment aperture.
11. Make small adjustments to the M7 horizontal and vertical tilt angle controls until the power level on the control box increases by at least 5%.
12. Translate BP1 (turn micrometer counterclockwise) into the beam path until the pump beam travels through 3-4 mm of the prism.
13. Toggle the controller AUTO RANGE/PEAK RESET switch to PEAK RESET. Open the aperture on M6.
14. Maximize the output power using the M7 vertical and horizontal tilt angle controls.

15. Maximize the output power using the M1 and P2 vertical and horizontal tilt angle controls.
16. Once the laser is optimized using M7, reduce the slit width (turn slit width control counterclockwise) until the output power is reduced approximately 50%.
17. Rotate the slit horizontal translation control for maximum output power. This centers the slit in the beam.
18. Repeat the previous two steps two or three times to ensure that the slit is centered.
19. Turn BP2 control clockwise until laser power drops to 50% of original power.
    - a.) Turn the BP2 control counterclockwise 4 turns if the BRF is set for a wavelength shorter than 730 nm.
    - b.) Turn the BP2 control counterclockwise 3 turns if the BRF is set for a wavelength between 730-960 nm.
    - c.) Turn the BP2 control counterclockwise 2 turns if the BRF is set for a wavelength longer than 960 nm.
20. Set the CW/ML/β-Lock switch on the controller to ML. Optimize the slit width control for maximum power with zero CW content as viewed on the controller display.
    - a.) The fast diode display from Mira Optima laser head can be displayed on a 50-ohm terminated oscilloscope to determine mode-locked operation (Figure 4-3).
    - b.) After the system is mode-locked, adjust the BP2 micrometer for optimum pulse width. The pulsewidth is monitored by using an autocorrelator.

Walking the Beam

"Walking the beam" refers to the procedure to adjust the beam position between two adjacent mirrors such as M2 and M3. This procedure is executed while the system is lasing.



Safety glasses must used when performing this alignment as stray beams could be present that pose significant safety hazards.

Assume that the beam is not striking M2 in the center. Walk the beam as follows:

1. Adjust the M3 vertical tilt angle control to move the beam in the direction to center the beam on M2 until the power has decreased approximately 20%.
2. Adjust M2 vertical and horizontal tilt angle controls to recover power.
3. Repeat step 1 and step 2 until the position on M2 is satisfactory. Each repetition of step 1 and step 2 moves the beam about 0.25 mm to 0.5 mm.
4. Performing step 1 through step 3 affects the beam position on all optics on the same side of the crystal.
5. Continue to walk the beam on all optics progressing to the end mirror as listed below.
   a.) M4, M3, M2, M1
   b.) M5, M8, M9. This is done in the auxiliary cavity as a preliminary step to aligning the main cavity
   c.) M5, M6, M7. This is done when using the main cavity, i.e. when prisms are in.

Setting BP1 and BP2 Rotational Position

The rotational position of Prisms BP1 and BP2 are set at the prism's minimum angle of deviation. This angle is wavelength-dependent but the dependence is so small for the wavelengths covered by any of the Mira's optic sets that it is sufficient to set the prisms at the center wavelength of the optics tuning range. If set properly, the optical alignment of the Mira is preserved during tuning, and the maximum amount of bandwidth (shortest pulse) is now possible.

The following procedure is conducted while operating in CW mode.

The rotational position of these prisms is critical for optimal tuning and pulsewidth. Do not rotate either BP1 or BP2 unless one of the prisms has been accidently moved from the factory setting

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1. As a coarse adjustment, rotate BP2 until the aluminum rod extending out of the base holding the prisms is approximately parallel to the micrometer controlling the translational position of the prism. If necessary, slightly loosen (less than 1/8 of a

turn) both set screws (located on the opposite side of the aluminum rod) securing the prism base to the translational stage.

2. Translate BP1 (counterclockwise) until the pump beam is refracted towards M6.

3. Rotate BP1 in either direction while observing the position of the pump beam in front of M6. The horizontal position of the pump beam swings from side to side. There is a single position to which the pump beam is refracted, as far to the right as possible, regardless of whether the prism is rotated clockwise or counterclockwise. Once at this position, the prism is set for the minimum angle of deviation of the pump beam.

4. To set the prisms to the minimum angle of deviation of the Mira Optima beam, slightly nudge BP1 clockwise until the position of the pump beam near M6 just begins to move. A more fine adjustment of BP1 may be necessary later in this procedure.

5. Complete step 1 to step 15 of the optical alignment detailed in the paragraph titled "Main Cavity Alignment".

6. Tune the laser to a wavelength about 30-40 nm shorter than the optics set center wavelength. It may be necessary to translate BP2.

   The tuning range of ± 40 nm translates the beam laterally about 10 mm through BP2. This translation is visible by looking at the propagation of the beam through BP2 with an IR viewer. The wavelength change of 80 nm causes the beam to translate from propagating through the tip of the prism to propagating through the base of the prism. Thus, it is not necessary to read the BRF micrometer or to use a spectrometer when testing the rotational position of the prisms. Simply rotate the BRF and observe the beam path in BP2.

7. Maximize the output power by adjusting the horizontal control of M7.

8. Tune the laser to a wavelength about 30-40 nm longer than the optics set center wavelength (it may be necessary to translate BP2).

9. Adjust the horizontal control of M7 for maximum power. If both BP1 and BP2 are set at the minimum angle of deviation then it should not be necessary to adjust the horizontal of M7 for maximum power at this longer wavelength.

10. If it was necessary to adjust the horizontal position of M7 to get the maximum power at the longer wavelength, rotate BP2

either clockwise or counterclockwise until the power drops 30-50%. Skip to step 12.

11. If it was not necessary to adjust the horizontal position of M7 to get the maximum power at the longer wavelength then the prisms are set correctly and this procedure is completed.
12. Repeat step 8 to step 11. If the amount of adjustment necessary on the M7 optic decreases, continue to rotate BP2 in the same direction (from step 11).
13. Lower the power drop between rotations from 30-50% to 5-10% as the correct angle is approached. If the amount of adjustment necessary on the M7 optic increases, reverse the direction of rotation of BP2.
14. Repeat step 8 to step 13 at different BP1 settings until the maximum power remains at both ends of the 60-80 nm tuning range.
15. If the condition in step 14 is unattainable, slightly nudge BP1 either clockwise or counterclockwise and repeat step 5 to step 14.

Advanced Alignment Techniques

Below is a brief description of some advanced alignment techniques that might improve the performance of the Mira Optima. It is not necessary to apply any of these procedures to a properly installed and well-maintained system, and none of these procedures must ever be attempted until after all of the basic alignment techniques (cleaning, end mirror alignment, beam walking, simple pump alignment) have been tried. These techniques are often only beneficial for the following situations:

- The pump source was changed or moved relative to the Mira.
- The long wave (> 950 nm) performance of the system has degraded and the normal alignment techniques do not improve the performance.
- When a marginal performance improvement is desired at a specific, single wavelength at the expense of the performance at other wavelengths.

The below procedures may be followed in no particular order, and is not necessary to follow every procedure.

Fine Pump Beam Alignment

This procedure is most beneficial if the pump beam was recently re-aligned or the pump source was changed. Under these circumstances it is possible to obtain up to 10% increase in CW power.

In this procedure, the pump horizontal and vertical translational knobs are the two knobs that control the P3 and P4 pump optics. The horizontal and vertical angle adjust knobs are the ones that control the P2 pump optic orientation. This entire procedure is performed while in CW mode.

1. Tune to a wavelength around the peak of the gain curve. Peak the system up in the main cavity. Use a stable wavelength, one where the CW power is not fluctuating.
2. Measure the power with a power meter. Because the beams are being aligned slightly in this procedure, the positional dependence of the Optima power meter can sometimes cause inaccurate adjustments to be made; i.e., it might indicate that the power is going up but it may simply be that the beam is moving.
3. Note the power as read on the external power meter. Turn the horizontal translational knob ¼- to ½-turn clockwise or counterclockwise.
4. Now compensate for the drop in power by adjusting the horizontal and vertical P2 angle adjust knobs, M7, and the output coupler. If the power went up repeat the process. If it went down, turn the horizontal translational knob in the other direction. Do not turn the knob by more than 1 complete revolution from the initial position. If it takes more than one turn to optimize the pump beam translational alignment, then it probably means that the entire pump beam needs to be re-aligned, which requires a visit from Coherent service.
5. Once finished, do not move the horizontal translational knob for the rest of this procedure.
6. Repeat step 3 to step 5 for the vertical translational knob. Once completed, do not move this knob for the rest of this procedure.
7. Turn the P2 horizontal angle adjust knob 1/8- to 1/4-turn clockwise or counterclockwise. Compensate for the drop in power by adjusting M7 and the output coupler. If the power went up, repeat the process. If it went down, turn the P2 horizontal angle adjust knob in the other direction. Do not turn the knob more than 1/2-turn from the initial position. Once finished, do not move the P2 horizontal angle adjust knob for the rest of this procedure.
8. Repeat the above step for the vertical angle adjust knob, peaking the laser by using only M7 and the output coupler.

9. Once completed, the horizontal and vertical translational adjust knobs must not be adjusted unless you plan to repeat this whole procedure. The P2 angle adjust knobs can be adjusted as needed to peak for power during the day or during initial system turn-on.

Pump Lens Position

This procedure is most beneficial if the pump beam was recently re-aligned or the pump source was changed. Under these circumstances, it is possible to obtain up to a 10% increase in CW power. In this procedure, the focal position of the pump beam inside the crystal is translated improve the modal overlap of the pump and intracavity beam.

This entire procedure is performed while in CW mode.

1. Tune to a wavelength around the peak of the gain curve. Peak the system up in the main cavity. Note the power as read on the Mira Optima Power meter.
2. Slowly loosen the 1/4-20 screw that secures the translational position of the pump lens mount. This is the screw next to the index marker. While loosening the screw, periodically peak up the CW power of the laser by turning the P2 horizontal and vertical angle adjust knobs.
3. Peak up the system power by turning the P2 horizontal and vertical angle adjust knobs, M7 and the output coupler
4. Translate the lens either forwards or backwards 1 mm or less. Peak up power by nudging the lens to one or the other side. Then peak up the power by turning the P2 horizontal and vertical angle adjust knob. If the power increases, continue to translate the lens in the same direction. If it decreases, move the lens in the other direction.
5. Once the position of maximum power is achieved, secure the translational position of the lens by tightening the 1/4-20 screw slowly. While tightening the screw, periodically peak up the CW power of the laser by turning the P2 horizontal and vertical angle adjust knobs.
6. Peak up the system power by turning the P2 horizontal and vertical angle adjust knobs, M7 and the output coupler.

Adjusting the In-Plane Alignment

This procedure is most beneficial if the long wave (> 960 nm) performance of the system has degraded and the normal alignment techniques do not improve the performance. It generally has no

effect on the system performance for wavelengths < 960 nm. In this procedure, the intracavity beam is walked to improve the parallelism of the beam relative to the Mira baseplate (i.e., the angle of incidence in the vertical plane for the intracavity optics is 90 degrees).

This procedure is performed while in CW mode.

1. Tune to a wavelength around the peak of the gain curve. Peak the system up in the main cavity. Note the power as read on an external power meter.
2. Adjust the vertical of M4 (clockwise or counterclockwise) until the number on the Optima power meter drops about 50%.
3. Adjust the vertical of M3 to recover as much of the power as possible.
4. Adjust the output coupler to maximize the power.
5. Iterate step 2 to step 4 for M4-M3 until the highest power on the external power meter is achieved.
6. Repeat step 1 to step 4 for M3-M2.
7. Repeat step 1 to step 4 for M2-M1.
8. Repeat step 1 to step 4 for M5-M6 (adjust the vertical of M5, compensate with M6, fine adjust with M7 and the output coupler.)
9. Repeat step 1 to step 4 for M6-M7.
10. Peak up the system power by turning the P2 horizontal and vertical angle adjust knobs, M7 and the output couple.

Additional Factory Adjustments

The below settings are additional parameters that are accessible to the end-user but are not customer adjustable. These parameters are factory-set. Performing any of the following adjustments may void the system's warranty. Contact Coherent service for guidance.

- M4-crystal, M5-crystal distance settings: These are often referred to as the d1 and d2 settings. The total distance between the mounts is called the z distance. These settings are factory-set for optimal performance throughout the entire tuning range. Among other characteristics, these settings influence CW power, ML power, the Kerr lensing, mode quality, and beam size.
- Crystal Face Normal: This adjustment rotates the optical axis of the crystal. It has a minor influence on CW skip tuning and beam polarization.

- BRF angle of incidence: The highest CW and ML power is obtained when the BRF is positioned such that the angle of incidence is at Brewster's angle for the intracavity beam.
- Starter angle of incidence: The highest CW and ML power is obtained when the starter is positioned such that the angle of incidence is at Brewster's angle for the intracavity beam.
- Crystal angle of incidence: The highest CW and ML power is obtained when the Crystal is positioned such that the angle of incidence is at an angle between the Brewster's angle for the intracavity beam and the pump beam.

OPERATOR'S MANUAL

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CHAPTER SIX
MAINTENANCE

COHERENT

Introduction

This chapter contains procedures for cleaning optics and for replacing .

Contaminated optics are the cause of many of the preventable problems in the operation of many lasers. Keeping the outside environment of the Mira Optima clean and free of dust will help avoid degradation of performance due to contamination.

If an optic must be replaced due to damage, or for changing an entire set of optics, refer to the appendix for the appropriate replacement optic part number. Use the optics replacement procedures detailed in this chapter.

Covers, Brewster windows

The covers of the Mira Optima provide a tight seal against the outside environment, and operating the laser with the covers on and latched will reduce contamination and the need to clean the optics. With the covers properly in place, the only optical surfaces exposed to the outer environment are the input Brewster window, where the pump laser enters the Mira Optima; and the output Brewster window, where the output of the Mira Optima exits. These windows must be checked periodically and cleaned carefully.

It is possible to clean the input and output Brewster windows while they are in place, using a few drops of methanol on lens tissue wrapped around a cotton swab. (In this case, block any beams that might hit the Brewster windows both during and for a few seconds after cleaning to allow any residue to evaporate from the surface being cleaned.)

Cleaning these windows easier and more effective by removing the assembly from the baseplate, or by removing only the piece containing the Brewster window from the assembly. When the window is put back in place, it must be seated against the inside of the body of the Mira Optima to restore the seal.

Cleaning Optics

In order to maintain optimum performance of high-grade optics, proper cleaning is an absolute necessity. Laser optical components are routinely exposed to high energy levels. When optical surfaces are clean, this energy is either reflected or transmitted. When optical coatings are contaminated, however, contaminants on the optical surface absorb energy, creating hot-spots that can burn the precision coating and dramatically reduce laser efficiency. Absorption caused by contaminated optical surfaces will degrade performance and shorten mirror life.

Contaminants that can cause absorption include a variety of particles that may fall on the optical surface or condense from surrounding vapors. Oils from the skin (even from the cleanest hands or transferred by contact with lens tissue used for cleaning), fibers of lens tissue themselves left on optics, or plastic gloves can be a source of contaminants. Exercise extreme care when handling and cleaning optics.

Spectroscopic/spectrophotometric-grade or electronic-grade acetone or methanol are the recommended solvents for cleaning optics. Other solvents and other grades can leave residues or otherwise degrade the coatings with which the they come in contact.

Lens tissue of high quality is the recommended material for cleaning optics. When cleaning optics with lens tissue, use each tissue for only *one* pass in *one* direction and then discard it. Do not reuse a tissue or swipe back in the opposite direction. Repeat if necessary with a clean tissue, going in the same direction as the original swipe. Reusing tissue or going back in the opposite direction may lead to damage of the optic by dragging loose particles back across the surface.

Cleaning Installed Optics

In the case of a large amount of dust visible on an optic, gently blowing a puff of air across an optic *may* be used as an initial step in cleaning. However, do *not* use compressed air that contains propellants, do *not* blow with your mouth, and do *not* use anything that contains any other residue or that may cause condensation on the optic. Also, be careful not to stir up dust in the air that will then settle on the optic.

The following procedure is used to clean optics while in place in the laser head. When possible, clean the optic while it is installed in the laser head to minimize disturbance to the optical alignment.

Exercise caution when cleaning the Brewster's prisms or when working near the prisms. A damaged prism will require a service call by a Coherent field service engineer to replace the damaged prism.

1. Block the pump laser beam. Remove the laser head cover.
2. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

3. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
4. Gently wipe across the optic in one direction. Use enough pressure to just make contact between the tissue and the optic, but no more. Take extreme care for those optics that might dislodge or brake off of their mounts.
5. Repeat the above steps until the optic is clean, using a new lens tissue for each pass.

Cleaning Removed Optics

The following technique is recommended for optics that have been removed from the laser or are being put into the laser.

1. Hold the optic element gently by the edge or place it on a clean work surface covered with lens tissue.
2. Place a few drops of acetone or methanol on one end of the lens tissue. Handle the optic gently while cleaning it to avoid microfine abrasions.
3. Place the wet end of the lens tissue on the optic and pull it across the optic in one direction only. Ensure that the optic does not move by holding it by the sides while doing this. Do not rub the tissue back and forth. Note that the dry part of the tissue helps remove any acetone or methanol residue.
4. Repeat the above steps until the optic is clean, using a new lens tissue for each pass. The slightest bit of contaminate is more readily seen by looking at the reflection of a bright light off the optic's surface.

Cleaning the Ti:Sapphire Crystal

The surfaces of the Ti:Sapphire are covered by aluminum dust covers. Despite these dust coverings, it is occasionally necessary to clean the crystal surfaces to maintain optimal laser performance. The crystal inside the Mira Optima does not have an optical coating. The Ti:Sapphire is very hard and is very unlikely (but not impossible) for the surface to become scratched. A more common occurrence, though also rare, is that the contaminate on the crystal surface can become burned. If the burn marks cannot be removed by the

following procedure, contact your local Coherent representative. In this unlikely occurrence the problem is solved easily by a slight translation of the crystal.

1. Block the pump laser beam. Remove the Mira Optima laser head cover.
2. Slide back the two dust covers that protect the crystal surfaces. Remove the entire dust cover by loosening the knurled thumbscrews on the M4 and M5 mounts (see Figure 3-3).
3. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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4. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
5. Gently wipe one of the surfaces of the crystal. Be careful to not drag any of the excess soft metal, located between the crystal and its aluminum mount, across the crystal face.
6. Replace the tissue and wipe the second face.
7. Visually verify that the contaminate has been removed and that the surface is not soiled.
8. Replace the dust covers and unblock the pump beam.

Mira Optima Optics Changes

There are five sets of optics for the Mira Optima laser. The optic sets are called short wavelength (SW), peak wavelength (PW), long wavelength (LW), extended wavelength (XW) and extended long wavelength (ELW). The part numbers for these sets are listed in the appendix.

Changing Wavelengths from Non-overlapping Wavelength Sets

This includes the following conditions:

- SW to LW
- SW to ELW
- PW to ELW
- ELW to PW
- ELW to SW
- LW to SW

Follow the next steps:

1. Remove the slit assembly.
2. Change all required optics (M1 through M9) using steps 1 through 3 in the optics replacement procedure for each optic.
3. Perform the full alignment procedure in Chapter Five, Installation and Alignment.

Changing Wavelengths between Adjacent Optic Sets

This includes the following conditions:

- From any set to XW
- SW to PW
- PW to LW
- LW to ELW
- ELW to LW
- LW to PW
- PW to SW
- XW to any set

Follow the next steps:

1. Remove the slit assembly.
2. Tune the laser to a wavelength in which the wavelength coverage of the two optic sets overlap. Refer to the wavelength calibration sheet for the correct micrometer setting.
3. Switch to the auxiliary cavity.
4. Starting with M4 then M5, replace optics M2 through M9 ending with M1, one optic at a time, using the optics removal and installation procedure for each optic.
5. Re-establish lasing after each optics replacement.

6. Return to the prism cavity
7. Replace M6 and M7. Follow the procedure in Chapter Five, Installation and Alignment, for aligning the main cavity.
8. Replace the slit assembly.
9. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

Optics Replacement

Use extreme care when removing optics from their mounts and do not touch the coated or polished surfaces.

The following procedure describes optic replacement. To change the wavelength range, perform steps 1 through 3 of the optic replacement procedures for each optic (M1 through M9) that is being replaced. Then, if necessary, perform the full alignment procedure in Chapter Five, Installation and Alignment. Replace only those optics required by the fact sheets to implement the wavelength change.

Equipment Used During Optic Replacement

- Optics set for new operating wavelength
- Accessory kit supplied with laser
- Power meter, Coherent FieldMaster or equivalent (0 to 10 Watts)
- Laser safety glasses to protect against the wavelength exiting the laser head and to protect against the pump beam wavelength
- Infrared (IR) viewer (required for conversions to/from LW or ELW optic sets).

M1 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation. Set the controller CW/ML/β-Lock select switch to continuous wave (CW).
2. Remove the slit assembly by removing the 2 mounting screws(Figure 3-4).

3. Loosen the setscrew on top of the output coupler M1 mount (Figure 3-4).

4. Remove the optic by pushing the optic from the output side with the soft end of a cotton swab.

5. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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6. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.

7. Gently wipe one of the surfaces of the optic, then the other.

8. Using lens tissue to avoid touching the optical surfaces, install the new optic with the flat side facing up, and the arrow on the side of the optic pointing towards M2. Tighten the setscrew.

9. Turn the cooling water to the crystal on and unblock the pump laser beam.

10. Set the CW/ML/β-Lock switch on the controller to CW.

11. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESSION that is the most sensitive display on the controller.

12. Close and adjust the M2 alignment aperture so the fluorescent reflection from M3 is centered in the aperture. If necessary, block the retroreflection from M1 in order to see the floréscence from M3 cleanly.

13. Locate the retro-reflection from M1 on the M2 aperture using an IR viewer.

14. Adjust the M1 horizontal and vertical tilt angle controls to center the retro-reflection in the aperture. In most cases, the system will begin to lase at this point.

15. Open the M2 aperture.

16. Adjust M1 horizontal and vertical tilt angle controls to maximize the fluorescence (or laser power) on the controller display. If the Mira Optima does not lase after maximizing the fluorescence, repeat the alignment procedure or refer to Figure 4-1.
17. Maximize the output power using M1, M7 (end mirror), and P2 horizontal and vertical tilt angle controls respectively.
18. Re-install the slit assembly.
19. Open the slit assembly by rotating the slit width control fully clockwise.
20. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

M2 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation. Set the controller CW/ML/β-Lock select switch to CW.
2. Remove the slit assembly by removing the two mounting screws (Figure 3-4).
3. Loosen the setscrew on the side of the M2 mount (Figure 3-9).
4. Remove the optic by carefully pushing on the optic with a cotton swab through a hole on the rear of the optic mount.
5. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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6. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
7. Gently wipe one of the surfaces of the optic, then the other.

8. Using lens tissue to avoid touching the optical surfaces, install the new optic with the arrow on the side of the optic pointing towards M1 and tighten the setscrew.
9. Turn the cooling water to the crystal on and unblock the pump laser beam.
10. Set the CW/ML/β-Lock switch on the controller to CW.
11. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
12. Adjust the M2 horizontal and vertical tilt angle controls to center the fluorescence on the M1 optic. A white card or an IR viewer may assist in centering the fluorescence.

    If the Mira Optima lases, proceed to the next numbered step.

    If the Mira Optima does not lase, adjust M2 horizontal and vertical tilt angle controls to maximize the fluorescence on the controller display. If the Mira Optima does not lase after maximizing the fluorescence, adjust the horizontal and vertical of M1 to retroreflect the beam onto M2. Refer to Figure 4-1.
13. Maximize output power using P2 and M7 horizontal and vertical tilt angle controls.
14. Block the pump beam and re-install the slit assembly. Open the slit assembly by rotating the slit width control fully clockwise.
15. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

M3 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Open the slit assembly by rotating the slit width control clockwise.
4. The M3 optic is very close to the butterfly. Avoid touching the butterfly during M3 removal. If the butterfly is accidentally touched, clean the butterfly after M3 installation is complete using the cleaning procedures in this chapter.
5. Loosen the setscrew on the side of the M3 mount (Figure 3-18).
6. With a cotton swab, carefully push the optic through a hole on the rear of the optic mount.

7. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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8. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
9. Gently wipe one of the surfaces of the optic, then the other.
10. Using lens tissue to avoid touching the optical surfaces, install the new optic with the arrow on the side of the optic pointing towards M2 and tighten the setscrew.
11. Turn the cooling water to the crystal on and unblock the pump laser beam.
12. Set the CW/ML/β-Lock switch on the controller to CW.
13. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
14. Adjust M3 horizontal and vertical tilt angle controls to center the fluorescence on the M2 optic. A white card or an IR viewer may assist in centering the fluorescence.

    If the Mira Optima lases, proceed to the next numbered step.

    If the Mira Optima does not lase, adjust M3 horizontal and vertical tilt angle controls to maximize the fluorescence on the controller display. If the Mira Optima does not lase after maximizing the fluorescence, refer to Figure 4-1.
15. Maximize output power using P2 and M7 horizontal and vertical tilt angle controls.
16. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

M4 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Open the slit assembly by rotating the slit width control clockwise.
4. Loosen two thumbnuts and remove the beam shield (Figure 3-21).
5. Remove the two knurled thumbscrews on the rear of the M4 mount (Figure 3-21) and remove the mirror holder and optic. Do not allow the thumbscrews to touch focusing lens L1.
6. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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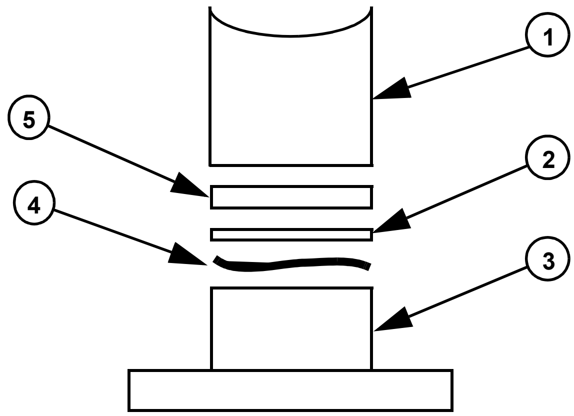
7. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
8. Gently wipe one of the surfaces of the optic, then the other.
9. Using lens tissue to avoid touching the optical surfaces, install the new optic into the holder with the arrow on the side of the optic pointing towards M5.
10. Place the optic holder in the mount and evenly tighten the two knurled thumbscrews (Figure 6-1).
11. Re-install the beam shield.
12. Turn the cooling water to the crystal on and unblock the pump laser beam.
13. Set the CW/ML/β-Lock switch on the controller to CW.
14. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
15. Follow the fluorescent spot from M4 to M1. Adjust the horizontal and vertical of M4 until the spot is centered on M1.



1. M4 optic
2. Flat washer
3. Optic holder
4. Bevel washer
5. O-ring

Figure 6-1. M4 Removal and Installation

If the Mira Optima lases, proceed to the next numbered step.

Maximize the fluorescence on the controller display. If the Mira Optima does not lase after maximizing the fluorescence, refer to Figure 4-1.

16. Maximize output power using P2 and M7 horizontal and vertical tilt angle controls.
17. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

M5 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Open the slit assembly by rotating the slit width control clockwise.
4. Loosen the two M5 assembly thumbscrews on the rear of the M5 mount (Figure 3-5) and remove the beam block.
5. Remove the smaller knurled screws from the rear of the mount and remove the optic holder.
6. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of

the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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7. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
8. Gently wipe one of the surfaces of the optic, then the other.
9. Using lens tissue to avoid touching the optical surfaces, install the new optic into the holder with the arrow on the side of the optic pointing towards M4.
10. Place the optic holder in the mount and evenly tighten the two knurled thumbscrews (Figure 6-1).
11. Turn the cooling water to the crystal on and unblock the pump laser beam.
12. Set the CW/ML/β-Lock switch on the controller to CW.
13. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
14. Follow the pump beam from M5 to M7 . Adjust the vertical of M5 until the spot is centered on M7 . Adjust the horizontal (and if necessary make small adjustments to the vertical) tilt angle control to maximize the fluorescence on the controller display.

    If the Mira Optima lases, proceed to the next numbered step.

    If the Mira Optima does not lase after maximizing the fluorescence, refer to Figure 4-1.
15. Maximize output power using P2 and M7 horizontal and vertical tilt angle controls.
16. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

M6 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Open the slit assembly by rotating the slit width control clockwise.
4. Loosen the setscrew on the side of the M6 mount (Figure 3-15).
5. With a cotton swab, carefully push the optic through a hole on the rear of the optic mount to remove it from the assembly.
6. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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7. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
8. Gently wipe one of the surfaces of the optic, then the other.
9. Using lens tissue to avoid touching the optical surfaces, install the new optic with the arrow on the side of the optic pointing towards BP2 and tighten the setscrew.
10. Turn the cooling water to the crystal on and unblock the pump laser beam.
11. Set the CW/ML/β-Lock switch on the controller to CW.
12. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
13. Record the BP1 micrometer reading.
14. Turn the BP1 micrometer clockwise (towards the lower reading) until it stops. This translates the prism out of the beam path. Refer to the optical schematic on Figure 2-2.
15. If the Mira Optima is lasing in the auxiliary cavity, proceed to the next numbered step.

If the Mira Optima does not lase:

- Use M8 vertical and horizontal tilt angle controls to position the pump beam reflection on the center of M9.
- Place a white card in front of M8 without blocking the pump beam. Several reflections may be visible.
- The correct retro-reflection is the brightest of the two reflections.
- Use a 3/32-in. Allen head wrench and M9 vertical and horizontal tilt angle controls to position the retro-reflection one beam diameter to the right of the pump beam on M8 (Figure 5-4).
- Make small adjustments to the M9 vertical and horizontal tilt angle controls to maximize the power on the controller display.

16. Maximize the output power using P2 and M1 vertical and horizontal tilt angle controls.
17. Turn BP1 micrometer translation adjust (Figure 3-2) counterclockwise to translate prism BP1 into the beam path until the output power is reduced by approximately 50%.
18. Place white card directly in front of M7. The laser alignment beam should be visible on the card. If necessary, use an IR viewer.
19. Close and adjust the M6 alignment aperture to center the aperture on the laser beam spot.
20. Locate the retro-reflection (from M7) on the M6 aperture face. Adjust the M6 horizontal and vertical tilt angle controls to position the retro-reflection from M7 back into the M6 alignment aperture. A 5 to 10% increase in the output power is observed when the beam is properly retro-reflected from M7 to M6.
21. Translate BP1 (turn micrometer counterclockwise) to the micrometer reading recorded in step 7.
22. Open the aperture on M6.
23. Maximize output power using the P2 and M7 horizontal and vertical tilt angle controls.
24. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment

M7 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Open the slit assembly by rotating the slit width control clockwise.
4. Loosen the setscrew on the side of the M7 mount (Figure 3-6)
5. With a cotton swab, carefully push the optic through a hole on the rear of the optic mount and remove it from the assembly.
6. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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7. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
8. Gently wipe one of the surfaces of the optic, then the other.
9. Using lens tissue to avoid touching the optical surfaces, install the new optic with the arrow on the side of the optic pointing towards BP2 and tighten the setscrew.
10. Turn the cooling water to the crystal on and unblock the pump laser beam.
11. Set the CW/ML/β-Lock switch on the controller to CW.
12. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
13. Record the BP1 micrometer reading. Turn the BP1 micrometer clockwise (towards the lower reading) until it stops. This translates the prism out of the beam path. Refer to the optical schematic on Figure 2-2.
14. If the Mira Optima is lasing in the auxiliary cavity, proceed to the next numbered step.

    If the Mira Optima is not lasing:

- Use M8 vertical and horizontal tilt angle controls to position the pump beam reflection on the center of M9.
- Place a white card in front of M8 without blocking the pump beam. Several reflections may be visible.
- The correct retro-reflection is the brightest of the two reflections.
- Use a 3/32-in. Allen head wrench and M9 vertical and horizontal tilt angle controls to position the retro-reflection 1/2- to 1-beam diameter to the right of the pump beam on M8 (Figure 5-4).
- If the system still is not lasing, place a white card after the M1 optic and before the BS1 beamsplitter. Two fluorescent spots should be seen, one slightly brighter than the other.
- Adjust the horizontal and vertical of M9 to overlap the dimmer spot with the brighter spot. Make small adjustments until the system lases.
- Make small adjustments to the M9 vertical and horizontal tilt angle controls to maximize the power on the controller display.

15. Maximize output power using P2 and M7 horizontal and vertical tilt angle controls.
16. Turn BP1 micrometer translation adjust (Figure 3-2) counterclockwise to translate prism BP1 into the beam path so that the output power is reduced by 50%.
17. Locate the beam on the M6 optic that is refracted from the auxiliary cavity.
18. Close and adjust the M6 aperture to center it on the refracted beam spot (it may be necessary to block the retro-reflection from M7).
19. Follow the reflection from M6 to BP2. If necessary, translate BP2 until the tip of the prism refracts the beam to M7.
20. Locate the beam on the M7 optic that is refracted from BP2. Adjust the M6 vertical tilt control until the beam at M7 is at the height of the alignment aperture.
21. Adjust the horizontal of M6 until the center wavelength of the optics set strikes within a 1 mm of the center of the M7 optic.
22. Locate the retro-reflected spot (from M7) on the M6 aperture face. Take note of the power reading on the Optima control box.

23. Adjust M7 horizontal and vertical tilt angle controls to position the retro-reflection into the M6 alignment aperture.
24. Make small adjustments to the M7 horizontal and vertical tilt angle controls until the power level on the control box increases by at least 5%.
25. Translate BP1 (turn micrometer counterclockwise) to the micrometer reading previously recorded.
26. Toggle the controller AUTO RANGE/PEAK RESET switch to PEAK RESET. Open the aperture on M6.
27. Maximize the output power using the M7 vertical and horizontal tilt angle controls.
28. Maximize output power using P2 and M1 horizontal and vertical tilt angle controls.
29. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

M8 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Open the slit assembly by rotating the slit width control clockwise.
4. Loosen the setscrew on the side of the M8 mount (Figure 3-2)
5. Remove the optic. The optic can be removed by carefully pushing the the optic with a cotton swab through a hole on the rear of the optic mount.
6. Clean both sides of the optic using the cleaning procedures.
7. Using lens tissue to avoid touching the surfaces, install the new optic and tighten the setscrew.
8. Turn the cooling water to the crystal on and unblock the pump laser beam.
9. Set the CW/ML/β-Lock switch on the controller to CW.
10. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
11. Record the BP1 micrometer reading.

12. Turn the BP1 micrometer clockwise (towards lower reading) until the pump laser beam is visible on the M8 optic.
13. Adjust M8 horizontal and vertical tilt angle controls to center the reflection on M9.
14. If the Mira Optima lases, proceed to the next numbered step.
    - If the system does not lase, place a white card after the M1 optic and before the BS1 beamsplitter. Two fluorescent spots should be seen, one slightly brighter than the other.
    - Adjust the horizontal and vertical of M8 to overlap the dimmer spot with the brighter spot.
    - Make small adjustments until the system lases.
    - If the Mira Optima still does not lase, make small adjustments to M8 horizontal and vertical tilt angle controls to maximize the fluorescence on the controller display. If it does not lase after maximizing the fluorescence, refer to Figure 4-1.
15. Turn the BP1 Micrometer counterclockwise to the setting recorded in step 6.
16. Maximize the output power using P2 and M1 horizontal and vertical tilt angle controls.
17. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

M9 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Open the slit assembly by rotating the slit width control clockwise.
4. Loosen the optic setscrew on the top of the M9 mount (Figure 3-19).
5. With a cotton swab, carefully push the optic through a hole on the rear of the optic mount and remove it from the assembly.
6. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To

avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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7. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
8. Gently wipe one of the surfaces of the optic, then the other.
9. Using lens tissue to avoid touching the optical surfaces, install the new optic and tighten the setscrew.
10. Turn the cooling water to the crystal on and unblock the pump laser beam.
11. Set the CW/ML/β-Lock switch on the controller to CW.
12. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
13. Record the BP1 micrometer reading. Turn the BP1 micrometer clockwise until the pump laser beam is visible on the M8 optic.
14. Adjust the M9 horizontal and vertical tilt angle controls to place the retro-reflection next to the pump beam on the M8 optic. See Figure 5-4.
    - If the Mira Optima lases, proceed to the next numbered step.
    - If the system is not lasing, place a white card after the M1 optic and before the BS1 beamsplitter. Two fluorescent spots should be seen, one slightly brighter than the other.
    - Adjust the horizontal and vertical of M9 to overlap the dimmer spot with the brighter spot. Make small adjustments until the system lases.
    - If the Mira Optima still does not lase, make small adjustments to M9 horizontal and vertical tilt angle controls to maximize the fluorescence on the controller display.
    - If it does not lase after maximizing the fluorescence, refer to Figure 4-1.
15. Turn the BP1 Micrometer counterclockwise to the setting previously recorded.

16. Maximize the output power using P2 and M1 horizontal and vertical tilt angle controls.
17. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

P0 Removal and Installation

1. Open the slit assembly by rotating the slit width control clockwise.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Record the BP1 micrometer reading. Turn the BP1 micrometer clockwise until the system is lasing in the auxiliary cavity and the pump laser beam is visible on the M8 optic.
4. With the Mira Optima lasing, note the position of the pump beam on the P4 optic (it should be centered). Center the alignment aperture on the pump beam in front of M9.
5. Block the pump laser beam from entering the Mira Optima. Turn the cooling water to the crystal off to prevent condensation.
6. Remove rear access panel.
7. Loosen the setscrew on the side of the P0 mount (Figure 3-10) and remove the optic.
8. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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9. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
10. Gently wipe one of the surfaces of the optic, then the other.
11. Using lens tissue to avoid touching the optical surface, install the new optic and tighten the setscrew.

12. Turn the cooling water to the crystal on. Set the pump laser power to 100 mW and unblock the pump beam.
13. Set the CW/ML/β Lock on the controller to CW.
14. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This will activates the DC SUPPRESS that is the most sensitive display on the controller.
15. Adjust the P0 vertical and horizontal tilt angle controls to center the pump beam in the center of P4 and through the alignment aperture in front of M9.
16. Verify that the pump beam is traveling through the center of the titanium:sapphire crystal. Turn pump laser up to normal operating power.
17. Remove the alignment aperture and set the pump to the normal operating power level.

    If the Mira Optima lases, proceed to the next numbered step.

    If the Mira Optima does not lase, make small adjustment to the P0 vertical and horizontal tilt angle controls until the system lases and then maximize the reading on the display.
18. Maximize the output power by adjusting the M9, M1, and P2 vertical and horizontal tilt angle controls.
19. Turn the BP1 Micrometer counterclockwise to the setting recorded in step 6.
20. Maximize the output power using M7, M1, and P2 horizontal and vertical tilt angle controls, respectively.
21. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

P1 Removal and Installation

1. Open the slit assembly by rotating the slit width control clockwise.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Record the BP1 micrometer reading. Turn the BP1 micrometer clockwise until the system is lasing in the auxiliary cavity and the pump laser beam is visible on the M8 optic.
4. While the Mira Optima lases, note the position of the pump beam on the P4 optic (it should be centered).

5. Center the alignment aperture on the pump beam in front of M9.
6. Block the pump laser beam from entering the Mira Optima. Turn the cooling water to the crystal off to prevent condensation.
7. Remove rear access panel.
8. Loosen the setscrew on the top of the P1 mount (Figure 3-9) and remove the optic.
9. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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10. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
11. Gently wipe one of the surfaces of the optic, then the other.
12. Using lens tissue to avoid touching the optical surface, install the new optic. Do not tighten the setscrew at this time.
13. Turn the cooling water to the crystal on, and set pump laser power to 100 mW and unblock the pump beam.
14. Set the CW/ML/β Lock on the controller to CW.
15. Hold the AUTO RANGE / PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This will activates the DC SUPPRESS that is thew most sensitive display on the controller.
16. Rotate the P1 optic until the pump beam is as close as possible to the center of P4. Tighten the setscrew on the top of the P1 mount.
    a.) If the pump beam is not centered on P4, small adjustments can be made to P1 by loosening the optic mount retaining screw. This will translate the pump beam horizontally on P4.

b.) To translate the pump beam vertically, loosen the optic mount retaining screw on the side of the P2 mount and make small angular changes until the pump beam is centered on P4.

17. Verify that the pump beam is passing through the center of the crystal assembly and is passing through the alignment aperture in front of M9.

    a.) If the pump beam is not centered, small changes can be made to the P3 mount.

    b.) Loosen the optic mount retaining screw and make small angular changes until the pump beam is centered on the alignment aperture.

    c.) Verify that the pump beam is still centered on P4, if it is not centered, go back and make small changes to P2.

    d.) Go between P2 and P3 and make sure that the pump beam is centered on P4 and the alignment aperture.

    e.) Remove the alignment aperture and set the pump to the normal operating power level.

    If the Mira Optima lases, proceed to the next numbered step.

    If the Mira Optima does not lase, make small adjustment to the P2 vertical and horizontal tilt angle controls and maximize the reading on the display.

18. Maximize the output power by adjusting the M9, M1, and P2 vertical and horizontal tilt angle controls.

19. Turn the BP1 Micrometer counterclockwise to the setting recorded in step 6.

20. Maximize the output power using M7, M1, and P2 horizontal and vertical tilt angle controls, respectively.

21. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

P2 Removal and Installation

1. Open the slit assembly by rotating the slit width control clockwise. Set the controller CW/ML/β-Lock select switch to CW.

2. Record the BP1 micrometer reading. Turn the BP1 micrometer clockwise until the system is lasing in the auxiliary cavity and the pump laser beam is visible on the M8 optic.

3. With the Mira Optima lasing, note the position of the pump beam on the P4 optic (it should be centered). Center the alignment aperture on the pump beam in front of M9.
4. Block the pump laser beam from entering the Mira Optima.
5. Turn the cooling water to the crystal off to prevent condensation.
6. Remove rear access panel.
7. Loosen the setscrew on the top of the P2 mount (Figure 3-9) and remove the optic.
8. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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9. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
10. Gently wipe one of the surfaces of the optic, then the other.
11. Using lens tissue to avoid touching the optical surface, install the new optic. Do not tighten the setscrew at this time.
12. Turn the cooling water to the crystal on.
13. Set pump laser power to 100 mW and unblock the pump beam.
14. Set the CW/ML/β Lock on the controller to CW.
15. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates the DC SUPPRESS that is the most sensitive display on the controller.
16. Rotate the P2 optic until the pump beam is as close as possible to the center of P4.
17. Tighten the setscrew on the top of the P2 mount. Manipulate the pump beam until it is centered on P4.

a.) To translate the pump beam horizontally on P4, loosen the optic mount retaining screw and make small angular changes.

b.) To translate the pump beam vertically, loosen the optic mount retaining screw on the side of the P2 mount and make small angular changes.

18. Verify that the pump beam is passing through the center of the crystal assembly and is passing through the alignment aperture in front of M9.

    a.) If the pump beam is not centered, loosen the optic mount retaining screw and make small angular changes until the pump beam is centered on the alignment aperture.

    b.) Go between P2 and P3 and make sure that the pump beam is centered on P4 and the alignment aperture.

    c.) Remove the alignment aperture and set the pump to the normal operating power level.

19. If the Mira Optima lases, proceed to the next numbered step. If the Mira Optima does not lase, make small adjustment to the P2 vertical and horizontal tilt angle controls and maximize the reading on the display.

20. Maximize the output power by adjusting the M9, M1, and P2 vertical and horizontal tilt angle controls

21. Turn the BP1 Micrometer counterclockwise to the setting previously recorded in step 6.

22. Maximize the output power using M7, M1, and P2 horizontal and vertical tilt angle controls, respectively.

23. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

P3 Removal and Installation

1. Open the slit assembly by rotating the slit width control clockwise. Set the controller CW/ML/β-Lock select switch to CW.

2. Record the BP1 micrometer reading. Turn the BP1 micrometer clockwise until the system is lasing in the auxiliary cavity and the pump laser beam is visible on the M8 optic.

3. With the Mira Optima lasing, note the position of the pump beam on the P4 optic (it should be centered). Center the alignment aperture on the pump beam in front of M9.

4. Block the pump laser beam from entering the Mira Optima.

5. Turn the cooling water to the crystal off to prevent condensation.
6. Remove rear access panel.
7. Loosen the setscrew on the bottom of the P3 mount (Figure 3-9) and remove the optic.
8. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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9. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
10. Gently wipe one of the surfaces of the optic, then the other.
11. Using lens tissue to avoid touching the optical surface, install the new optic. Do not tighten the setscrew at this time.
12. Turn the cooling water to the crystal on, and set the pump laser power to 100 mW and unblock the pump beam.
13. Set the CW/ML/β Lock on the controller to CW.
14. Hold the AUTO RANGE / PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This will activates the DC SUPPRESS that is the most sensitive display on the controller.
15. Rotate the P3 optic until the pump beam is as close as possible to the center of P4.
16. Tighten the setscrew on the bottom of the P3 mount. If the pump beam is not centered on P4, make small angular changes and adjustments to P1 and P4 until the beam is centered.
    a.) To translate the pump beam horizontally on P4, loosen the optic mount retaining screw.
    b.) To translate the pump beam vertically, loosen the optic mount retaining screw on the side of the P2 mount.

17. Verify that the pump beam is passing through the center of the crystal assembly and is passing through the alignment aperture in front of M9. If the pump beam is not centered, make small changes to the P3 mount.
    a.) Loosen the optic mount retaining screw and make small angular changes until the pump beam is centered on the alignment aperture.
18. Verify that the pump beam is still centered on P4. If the beam is not centered, go back and make small changes to P2.
19. Go between P2 and P3 and make sure that the pump beam is centered on P4 and the alignment aperture.
20. Remove the alignment aperture and set the pump to the normal operating power level.
21. If the Mira Optima lases, proceed to the next numbered step.
    a.) If the Mira Optima does not lase, make small adjustments to the P2 vertical and horizontal tilt angle controls and maximize the reading on the display.
22. Adjust the M9, M1, and P2 vertical and horizontal tilt angle controls to maximize the output power.
23. Turn the BP1 Micrometer counterclockwise to the setting previously recorded.
24. Maximize the output power using M7, M1, and P2 horizontal and vertical tilt angle controls, respectively.
25. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

P4 Removal and Installation

1. Open the slit assembly by rotating the slit width control clockwise. Set the controller CW/ML/β-Lock select switch to CW.
2. Record the BP1 micrometer reading. Turn the BP1 micrometer clockwise until the system is lasing in the auxiliary cavity and the pump laser beam is visible on the M8 optic.
3. With the Mira Optima lasing, note the position of the pump beam on the P4 optic (it should be centered). Center the alignment aperture on the pump beam in front of M9.
4. Block the pump laser beam from entering the Mira Optima.
5. Turn the cooling water to the crystal off to prevent condensation.

6. Remove rear access panel.
7. Loosen the setscrew on the side of the P4 mount (Figure 3-9) and remove the optic.
8. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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9. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
10. Gently wipe one of the surfaces of the optic, then the other.
11. Using lens tissue to avoid touching the optical surface, install the new optic. Do not tighten the setscrew at this time.
12. Turn the cooling water to the crystal on.
13. Set pump laser power to 100 mW and unblock the pump beam.
14. Set the CW/ML/β Lock on the controller to CW.
15. Hold the AUTO RANGE / PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates the DC SUPPRESS that is the most sensitive display on the controller.
16. Rotate the P4 optic until the pump beam is as close as possible to the center the alignment aperture in front of M9. Tighten the setscrew on the side of the P4 mount.
17. If the pump beam is not centered through the alignment aperture in front of M9, make small adjustments to P4 and angular changes to the P3 mount until the pump beam is centered on M9.
    a.) To translate the pump beam horizontally on M9, loosen the optic mount retaining screw.
    b.) To translate the pump beam vertically, loosen the optic mount retaining screw on the side of the P3 mount.

18. Verify that the pump beam is passing through the center of the crystal assembly and is centered on P4. If the pump beam is not centered, make small changes to the P2 mount.
    a.) Loosen the optic mount retaining screw and make small angular changes until the pump beam is centered on P4.
19. Verify that the pump beam is still centered through the alignment aperture in front of M9.
    a.) If it is not centered, loosen the optic mount retaining screw and make small adjustments to P2.
    b.) Go between P2 and P3 and make sure that the pump beam is centered on P4 and the alignment aperture is in front of M9.
20. Remove the alignment aperture and set the pump to the normal operating power level. If the Mira Optima lases, proceed to the next numbered step.
    a.) If the Mira Optima does not lase, make small adjustment to the P2 vertical and horizontal tilt angle controls and maximize the reading on the display.
21. Maximize the output power by adjusting the M9, M1, and P2 vertical and horizontal tilt angle controls.
22. Turn the BP1 Micrometer counterclockwise to the setting previously recorded.
23. Maximize the output power using M7, M1, and P2 horizontal and vertical tilt angle controls, respectively.
24. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

L1 Removal and Installation

1. Open the slit assembly by rotating the slit width control clockwise. Set the controller CW/ML/β-Lock select switch to CW.
2. Record the BP1 micrometer reading. Turn the BP1 micrometer clockwise until the system is lasing in the auxiliary cavity and the pump laser beam is visible on the M8 optic.
3. With the Mira Optima lasing, center the alignment aperture on the pump beam in front of M9, if lens L1 is not badly damaged. If the lens is too badly damaged to lase, assume the system was aligned such that the pump beam would strike the center of M9.

4. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
5. Adjust the pump laser so that the output power is approximately 100 mW.
6. Using an Allen wrench, loosen the setscrew on the top of the L1 mount (Figure 3-16) and remove the optic.
7. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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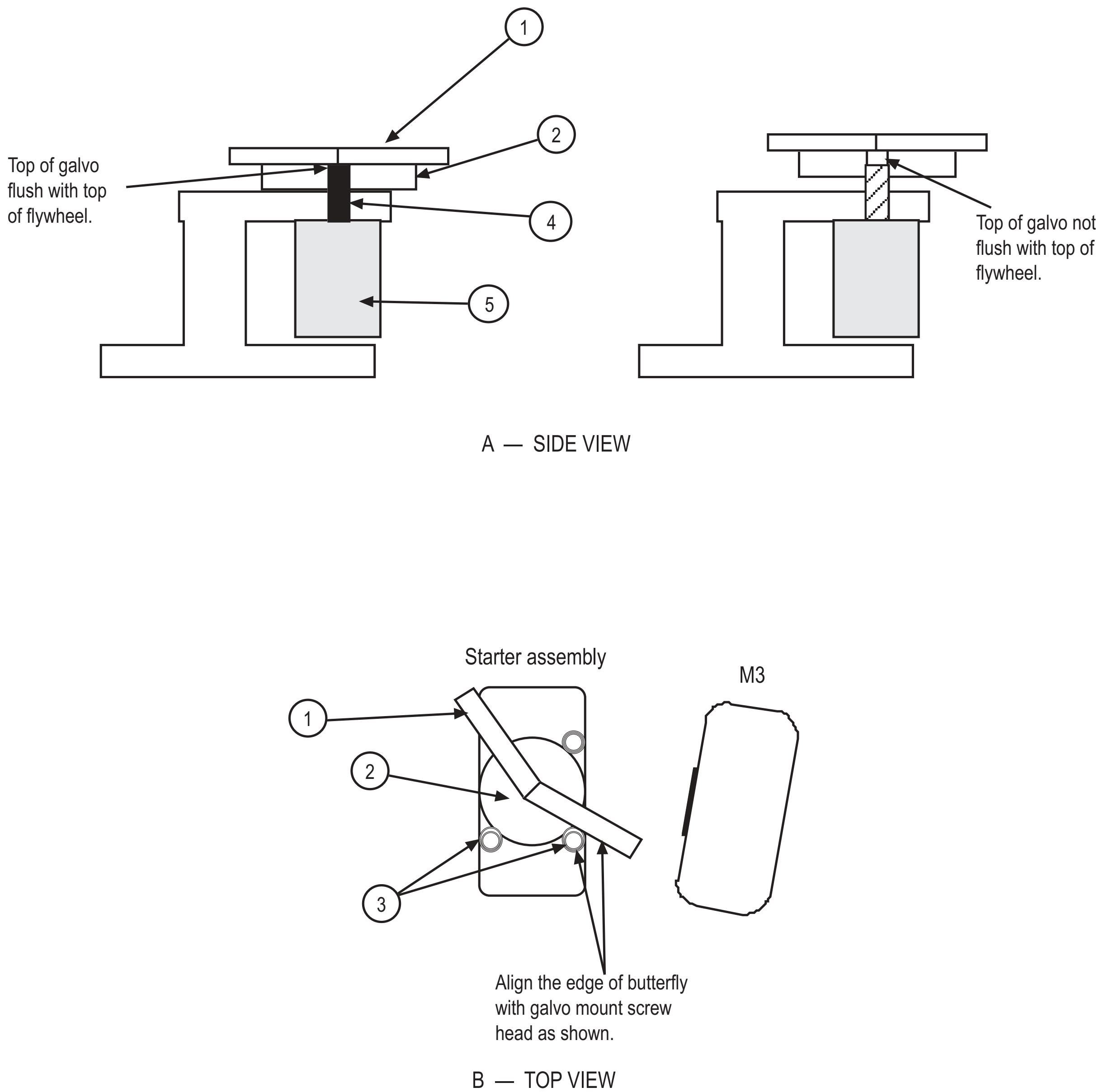
8. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
9. The lens has a curved side and a flat side. Gently wipe one of the surfaces of the lens, then the other.
10. Using lens tissue to avoid touching the optical surfaces, install the new optic with the flat side facing M4.
11. Tighten the setscrew.
12. Turn the crystal assembly cooling water on and unblock the pump laser beam.
13. Loosen the two 3/32 in. screws that hold the lens holder onto the translation stage so that the holder doesn't slip.
14. Adjust the position of the lens so that the pump beam is centered on the aperture in front of M9 or centered on the optic (see step 3).
15. Tighten the screws.
16. Verify that the pump beam is still centered on the aperture in front of M9 or centered on the optic. If not, repeat step 14.
17. Retract the beam shields (Figure 3-21) and verify that the beam is passing through the center of the crystal. The beam should also pass through the center (within 1 mm) of M4.
18. Set the CW/ML/b-Lock switch on the controller to CW.

19. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESS that is the most sensitive display on the controller.
20. Adjust the pump laser to the normal operating power level.
21. If the Mira Optima lases, proceed to the next numbered step.

    If the Mira Optima does not lase, adjust the P2 pump controls and maximize the fluorescence on the controller display. If it still does not lase after maximizing the fluorescence, refer to Figure 4-1.
22. Maximize the output power by adjusting the M9, M1, and P2 vertical and horizontal tilt angle controls
23. Turn the BP1 Micrometer counterclockwise to the setting recorded in step 6.
24. Maximize the output power using M7, M1, and P2 horizontal and vertical tilt angle controls, respectively.
25. Mode-lock the Mira Optima following the procedure in Chapter Four, Daily Operation, or Chapter Five, Installation and Alignment.

Starter Butterfly Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW. Open the slit assembly by rotating the slit width control clockwise.
3. Loosen the two setscrews (Figure 3-18) that secure the butterfly assembly on the galvo shaft, and remove the old butterfly starter.
4. Place the new butterfly assembly on the galvo shaft such that the top of the galvo shaft makes contact with the bottom of the butterfly starter (Figure 6-2A, left). Do not tighten the mounting setscrews at this point.
5. Position the butterfly as shown in Figure 6-2B, which is a coarse Brewster's angle alignment.
6. Raise the butterfly starter slightly (~0.5 to 1 mm) and tighten the mounting set screws (Figure 6-2A, right).
7. Clean all four long sides of the butterfly starter. (See step 7 though step 10 in the previous procedure.)
8. Turn the water to the crystal on, and unblock the pump laser beam.



1. Starter assembly butterfly
2. Stainless steel flywheel
3. Allen head screws (4)
4. Galvo shaft
5. Galvo

Figure 6-2. Starter Butterfly Installation

9. Tune the Mira Optima to a wavelength near the peak of the tuning curve.
10. Note the output power as indicated on the control box. Loosen the starter assembly Allen head screw (Figure 3-18) that secures the starter mount to the Mira Optima baseplate.

11. Slowly rotate the entire starter assembly clockwise or counter-clockwise while watching the power level. Position the starter assembly at the maximum CW power level.
12. Tighten the starter assembly using the Allen head screw.
13. Clean the butterfly while holding the stainless steel flywheel to prevent the shaft from turning. (See step 7 though step 10 in the previous procedure.)
14. To re-assemble, follow steps 5 through 1 in the opposite order, and tighten the screws when the step indicates to loosen them.

Brewster Prism (BP1/BP2) Removal and Installation

Under normal Mira Optima operation and maintenance, the Brewster prisms do not require removal and installation. In the event that BP1 or BP2 become scratched or broken, use the following procedure to replace them.

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW. Open the slit assembly by rotating the slit width control clockwise.
3. Loosen the Brewster prism assembly setscrews located on the opposite side of the aluminum rod and remove the prism assembly (Figure 3-2 or Figure 3-7).
4. Remove the lever arm from the damaged assembly and install it on the new assembly.
5. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

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6. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
7. Gently wipe all of the surfaces of the prism.

8. Using lens tissue to avoid touching the optical surfaces, install the new prism assembly so that the lever arm is parallel (by eye) to the micrometer.
9. Tighten the prism assembly setscrews so the prism can be moved freely but with enough friction so the prism will not be moved inadvertently.
10. Turn the crystal assembly cooling water on and unblock the pump laser beam.
11. Rotate the prism assembly to maximize the power displayed on the control box.
12. If the Mira Optima lases, proceed to the next numbered step.

    If the Mira Optima does not lase, perform the procedure "Setting PB1 and BP2 Rotational Position" for setting the rotational position of the prisms
13. Tighten the prism assembly setscrews.
14. Maximize the output power using M7, M1, and P2 horizontal and vertical tilt angle controls, respectively.

Setting BP1 and BP2 Rotational Position

The rotational position of Prisms BP1 and BP2 are set at the prism's minimum angle of deviation. This angle is wavelength-dependent, but the dependence is so small for the wavelengths covered by any of the Mira's optic sets that it is sufficient to set the prisms at the center wavelength of the optic's tuning range. If set properly, the optical alignment of the Mira is preserved during tuning and the maximum amount of bandwidth (shortest pulse) is possible.

The following procedure is conducted while operating in CW mode.

The rotational position of these prisms is critical for optimal tuning and pulsewidth. Do not rotate either BP1 or BP2 unless one of the prisms has been changed from the factory setting.

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1. As a coarse adjustment, rotate BP2 until the aluminum rod extending out of the base holding the prisms is parallel (by eye) to the micrometer controlling the translational position of the prism.

    If necessary, loosen both set screws located on the opposite side of the aluminum rod slightly (less than 1/8 of a turn) that secure the prism base to the translational stage.

2. Translate BP1 (counterclockwise) until the pump beam is refracted towards M6.
3. Rotate BP1 in either direction while observing the position of the pump beam in front of M6. The horizontal position of the pump beam swings from side to side. There is a single position that the pump beam is refracted as far to the right as possible (regardless of whether the prism is rotated clockwise or counterclockwise). Once at this position the prism is set for the minimum angle of deviation of the pump beam. To set the prisms to the minimum angle of deviation of the Mira Optima beam, slightly nudge BP1 clockwise until the position of the pump beam near M6 just barely begins to move. A more fine adjustment of BP1 may be necessary later in this procedure.
4. Complete steps 1 through 15 of the optical alignment detailed in "Main Cavity Alignment" on page 23.
5. Tune the laser to a wavelength about 30-40 nm shorter than the optics set center wavelength. It may be necessary to translate BP2 to achieve this wavelength.

   The tuning range of ± 40 nm laterally translates the beam about 10 mm through BP2. This translation is easily visible with an IR viewer at the propagation of the beam through BP2.

   The wavelength change of 80 nm causes the beam to translate from propagating through the tip of the prism to propagating through the base of the prism. Therefore, it is not necessary to read the BRF micrometer or to use a spectrometer when testing the rotational position of the prisms. Simply rotate the BRF and observe the beam path in BP2.
6. Maximize the output power by adjusting the horizontal control of M7.
7. Tune the laser to a wavelength about 30-40 nm longer than the optics set center wavelength (it may be necessary to translate BP2).
8. Adjust the horizontal control of M7 for maximum power. If both BP1 and BP2 are set at the minimum angle of deviation, it should not be necessary to adjust the horizontal of M7 for maximum power at this longer wavelength. Adjust the horizontal control of M7 for maximum power.
9. If the horizontal position of M7 was adjusted to get the maximum power at the longer wavelength, rotate BP2 either clockwise or counterclockwise until the power drops 30-50%.

   If it was not necessary to adjust the horizontal position of M7

to get the maximum power at the longer wavelength, then the prisms are set correctly and this procedure is complete.

10. Repeat step 5 to step 9. If the amount of adjustment necessary on the M7 optic decreases, continue to rotate BP2 in the same direction (from step step 9).
11. Lower the power drop between rotations from 30-50% to 5-10% as the correct angle is approached. If the amount of adjustment necessary on the M7 optic increases, reverse the direction of rotation of BP2.
12. Repeat step 5 to step 11 at different BP1 settings until the maximum power remains at both ends of the 60-80 nm tuning range.
13. If the condition in step 12 is unattainable, nudge BP1 slightly either clockwise or counterclockwise and repeat step 4 to step 12.

OPERATOR'S MANUAL

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CHAPTER SEVEN
THEORY OF OPERATION

COHERENT

Introduction

A laser is an optical oscillator that creates a very highly directed beam of light at a precise wavelength or frequency.

There are four important components of all lasers:

1. Energy (pump) source
2. Gain medium
3. High reflector
4. Output coupler/partial reflector

The region of space between the high reflector and the output coupler is referred to as the laser cavity.

If the atoms in the gain medium are properly “prepared”, light passing through the medium will be intensified, or amplified. The high reflector at one end of the laser, and the output coupler (or partial reflector), are aligned to cause the amplified light to return to the gain medium for further amplification. The light traveling strictly perpendicular to the high reflector and output coupler will make many passes through the gain medium without zigzagging off the mirrors and therefore be amplified significantly. This strong “preferential treatment” of light moving in a precise direction is what gives the laser its highly directed beam.

The output of the laser is simply a sampling of the light circulating in the cavity provided by the output coupler. The output coupler reflects most of the light incident on it but allows a fraction to be transmitted, forming the output of the laser.

The Gain Medium

In most materials, light is absorbed rather than amplified. The atomic explanation of absorption and amplification are similar; the difference is in the initial state of the atom.

Atoms are normally in their low energy state and pick up energy from incident light, thus absorbing the light. Upon absorbing this light, the atom is in an energetic state, and, when stimulated properly, falls to its original state and in doing so, emits light.

Atoms in their energetic or excited state can be stimulated to emit light using light itself. If, moreover, the stimulating light and the stimulated light are identical in wavelength, more light of that wavelength leaves the region of the atom than arrived there. This light is “amplified”.

Preparing the Atoms for Amplification — Pumping

Some means are required to raise the atoms to their high energy or excited state, because (at normal temperatures) most are in a lower energy state and will absorb rather than emit light. This process is referred to as pumping.

There are many methods of pumping, and different methods are appropriate for different atoms. In the case of the titanium:sapphire laser, another laser is required as the pump laser. In order to excite Titanium, each atom requires intense light and only a laser can provide this highly focussed and directed light.

Longitudinal Modes

Only certain wavelengths will be amplified, depending on the details of the amplifying medium and the mirrors. The wavelength may be further restricted by filters or other devices. In the case of Mira Optima all three are employed.

The titanium:sapphire itself will amplify anywhere from 680 nm to 1100 nm. The laser mirrors can restrict the wavelength range further and the birefringent filter (BRF) selects a relatively narrower portion within this range. The wavelength is restricted even further, due to a resonance condition similar to the vibrating frequencies of a string.

Each lasing wavelength must be precisely an integral number of half wavelength that must "fit" between the mirrors. Since the integer is not specified, there can be many wavelengths that satisfy this criterion. Each of the wavelengths is referred to as a "longitudinal mode".

Transverse Mode

The light contained between the mirrors within a very well-defined volume is much narrower than the physical diameter of the mirrors. This distribution is referred to as the "transverse mode" of the laser.

The diameter of the beam anywhere within the laser cavity depends specifically on the distance between the mirrors. This is important to understand the principle upon which Mira Optima operates.

Theory of Mode-locking

The following explanation of mode-locking is presented in its simplest form, but is sufficient to explain the operation of Mira Optima.

Within the cavity of a mode-locked laser, a single short pulse of light bounces back and forth between the mirrors.

At each bounce from the output coupler, a small portion of the pulse escapes to form the output of the laser. The time between pulses is equal to the time it takes for light to make one round trip from the output coupler to the high reflector at the other end of the cavity back to the output coupler. In the case of the Mira Optima, this time is approximately 13.2 ns. Time and frequency are inversely related, so the inverse of this time is the number of pulses per second, commonly referred to as the repetition rate, rep rate, or sometimes as the “frequency”. For Mira Optima, the rep rate (or frequency) is 76 MHz.

Once a pulse is formed within the cavity, most atoms that were in their excited state—i.e. prepared to emit light—have been stimulated by the passage of the pulse through the gain medium. For a period of time then after passage, there are insufficient atoms in the excited state to form and amplify another pulse. This means that only a single pulse is formed at a time, and the output consists of a sample of this one pulse, as it periodically arrives at the output coupler.

See the section titled “Origin of the Term “Mode-locked”” on page 7-9 for more information on mode-locking.

Formation of the Pulse

Active Mode-locking

Many techniques for creating this pulse have been developed. All techniques, however, act upon the laser in basically the same way.

In order to initiate the pulse, some sort of optical shutter (referred to as a “modulator”) opens, closes, and opens at precisely the correct rate to allow a pulse of light to pass through the shutter as it travels back and forth between the high reflector and output coupler. Only light that arrives at the shutter at precisely the correct time to pass through without being blocked will be amplified. Because the shutter is closed at all other times, a second pulse cannot be formed.

The timing of the shutter is extremely important and must be precisely equal to the time interval between successive bounces of the pulse to be amplified. In other words, the modulator frequency

must be precisely equal to the repetition rate (pulse frequency). If this technique must be used to form the mode-locked pulse, great care and ingenuity must be employed to keep these two frequencies identical. Since the time between pulses depends on the length of the cavity, any change in the length of the cavity must be accompanied by an accurate readjustment of the modulator frequency.

Alternatively, the cavity length can be regulated such that the repetition rate always matches the modulator frequency. There are many very practical commercial systems (e.g., YAG and YLF lasers) that use this type of mode-locking successfully—through ingenuity, precision components and competent engineering—despite the complexity of design.

Passive Mode-locking

A shutter or modulator with timing accurately controlled externally is not necessary in some mode-locked systems. If some material or mechanism is used that automatically opens to allow the pulses through but is closed otherwise, a self-adjusting modulator could be constructed.

In other words, the light pulse would open its own shutter when it arrives, rather than depending on it opening according to a timing mechanism upon arrival. Therefore, if the pulse arrives early or late, the shutter would still open on-time, allowing the pulse to pass through and then close. This method is referred to as passive mode-locking.

There are materials that behave in this manner. This is possible because the instantaneous intensity of the pulses are extremely high compared to the intensity when the laser is operating unpulsed or continuously (referred to as CW operation).

Some examples of this material include organic dyes that are normally opaque but become transparent to light of very high intensity. This intensity-dependent transmission is referred to as "saturable absorption". Unfortunately, these saturable absorbers are commonly exotic dyes with properties that are very wavelength-dependent. They often exist in liquid form and must either be refreshed frequently or flowing constantly. In addition, the dye concentration must be adjusted as the laser power changes.

Mira Optima's Saturable Absorber System

Coherent's engineering team has successfully designed a saturable absorber system that does not suffer from the limitations described above. It uses no dyes or liquids, does not have to be renewed, operates independently of wavelength, and is adjusted for various powers using a simple mechanical control.

The Mira Optima cavity was designed such that the beam diameter within the cavity changes by a small amount as the intensity of the light changes. More specifically, the beam diameter at certain locations within the cavity is large when the laser is operating continuously (CW) but becomes smaller when the laser is producing high intensity mode-locked pulses.

A simple slot or "slit" with adjustable width is located at the appropriate location, so the large diameter laser beam associated with continuous operation is interrupted at its edges. A high-intensity pulse, however, will pass uninterrupted through the slit because the beam is smaller. Once the laser is operating in pulsed mode, the small loss introduced by the slit is typically enough to completely extinguish the CW beam. Refer to Figure 7-1.

The mode-locking device in Mira Optima is a saturable absorber system, because, in reality, it consists of two parts:

1. A material that decreases the laser beam size in the presence of high intensity pulses
2. The slit that introduces losses for large beams

Changing the Beam Diameter

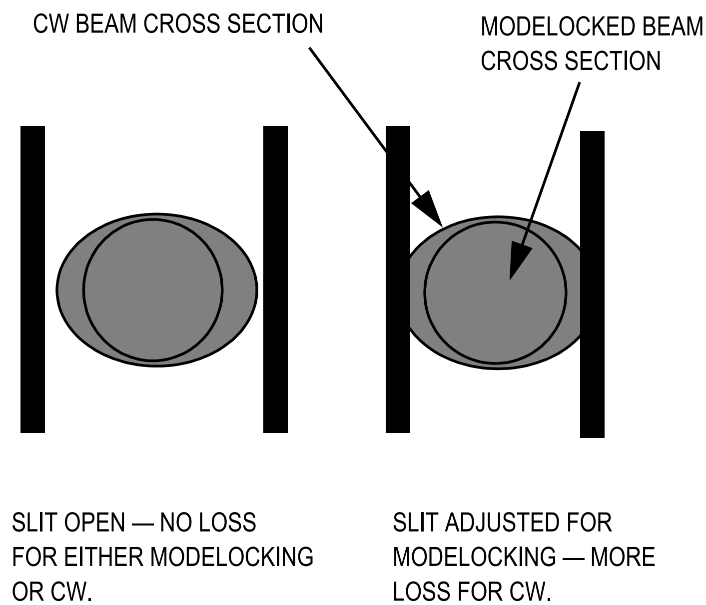
The properties of light passing through any material depends on a property referred to as the index of refraction, or *n*.

The index of refraction manifests itself in two primary ways.

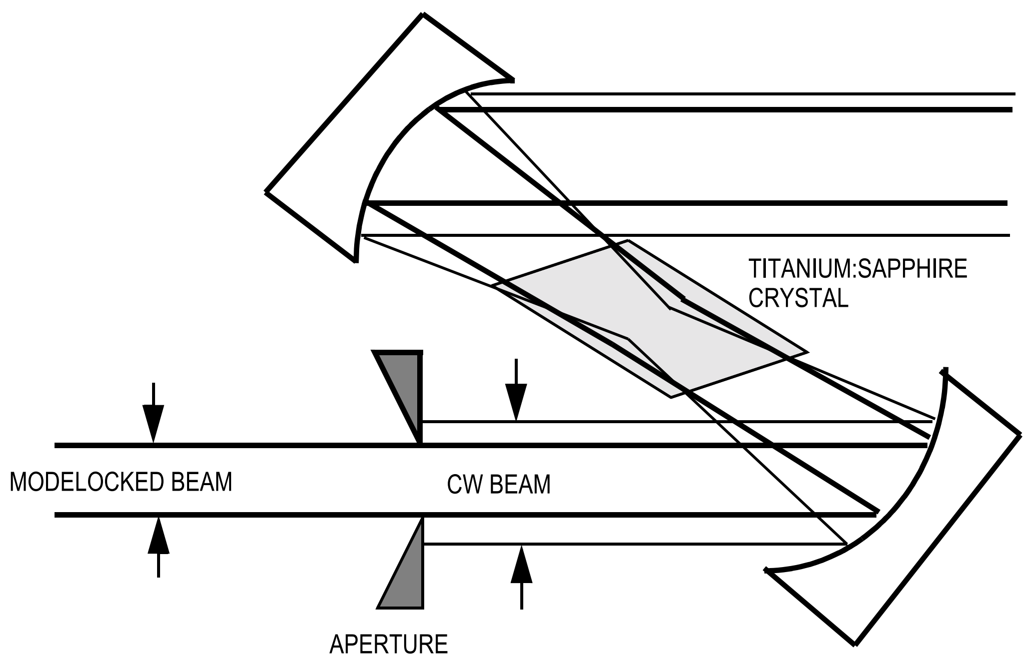
1. The velocity of light in a material is equal to the speed of light in a vacuum divided by the index of refraction. Thus, the higher the index of refraction (*n*), the lower the velocity of light.
2. The amount that a beam bends when it strikes a surface is defined by *n* (according to Snell's law). If the velocity of light is different for different parts of the light beam (that is, a spatially dependent *n*), then the beam will bend or otherwise be reshaped. This is known as refraction.

A common refractive element is the lens (e.g., a biconvex lens), which is thicker in the middle than at the edges, so that the center of the beam is slowed down more than the edges. This causes the light to bend toward the center. In the case of the lens, the index of refraction is the same everywhere, but since there is more glass in the middle than the edges, the edges are slowed down less.

A lens can also be formed by making the index of refraction at the center of the material larger than the index at the edges. This will also bend light and is referred to as a gradient index lens.



A. BEAM CROSS SECTION



B. BEAM GEOMETRY

Figure 7-1. Mira Optima Saturable Absorber System

The most common way to change the index of a material is to change its chemical composition. However, in Mira Optima, the index is changed by the light itself. At sufficiently high intensity, the electric

fields associated with the light can actually distort the atoms of the material and alter its index. This effect is known as the optical Kerr effect. The beam is less intense at its edges as compared to the center, the index at the center is different, and a gradient index lens is formed. Because the optical Kerr effect alters the index, the lens thus formed is referred to as a Kerr lens.

The Kerr lens is formed only when the intensity of the light is extremely high. The instantaneous intensity of mode-locked light pulses are sufficient to form this lens, but the weak intensity of the laser that is operating CW is not. Therefore, the lens is only formed upon the arrival of a mode-locked pulse. It is this lens that narrows the laser beam, and, consequently, a mechanism has now been created that narrows the beam only for mode-locked pulses. The addition of a slit to allow only narrow beams to pass unattenuated now forms the complete saturable absorber system, which provides a real driving force for mode-locking.

Origin of the Term "Mode-locked"

From the explanation above, it is not obvious why this pulsed output operation is referred to as "mode-locked". As mentioned in the laser description section, the laser can operate at a number of wavelengths that satisfy the condition that an integral number of half wavelengths will "fit" between the high reflector and output coupler. Any one of the wavelengths that satisfy this condition is called "Longitudinal Modes". When several modes are lasing simultaneously, they add to each other, so on a random basis, there are instants at that the light from all the modes will add together, to create an intense sum.

The larger the number of modes, the higher the instantaneous intensity. Figure 7-2 shows the intensity of light with varying number of modes, randomly phased or timed.

If the phase between each mode is adjusted non-randomly and held constant, the peak powers become much larger and the random spiking between these pulses diminishes. This is referred to as locking the modes together, hence the term "mode-locking".

Once the modes are locked together, it can be shown that the larger the number of modes locked together, the higher the pulse intensity and the narrower the pulse. Interestingly, the frequency of the pulses exiting the laser is precisely equal to the frequency separation of adjacent longitudinal modes.

The Starting Mechanism

Normally, the laser will operate in the CW mode with minor power fluctuations, none of which cause—even instantaneously—powers that are sufficiently high to cause a Kerr lens to form. Therefore,

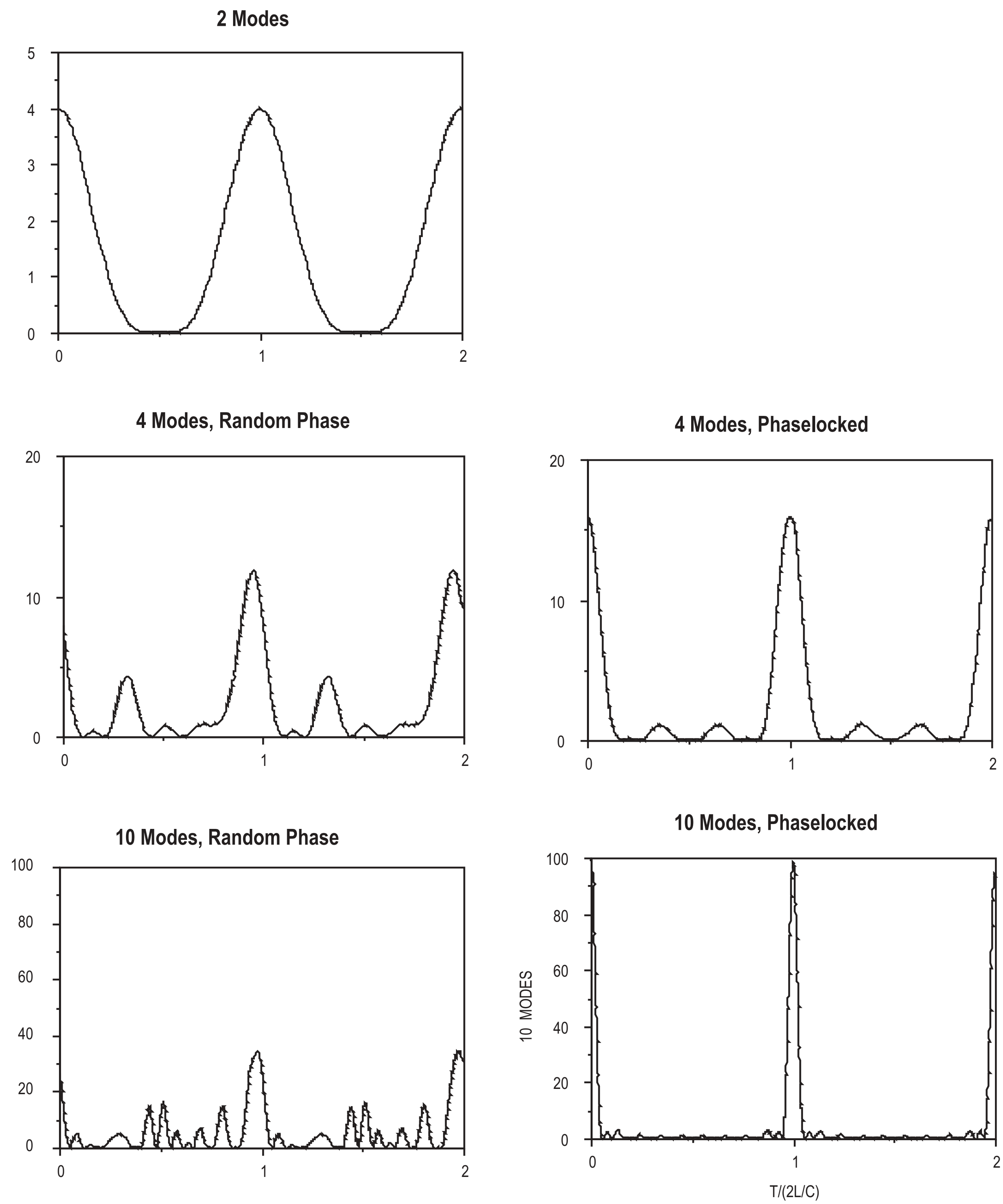


Figure 7-2. Intensity of Light with Varying Number of Modes
(note the difference in the vertical scales)

some mechanism must be introduced to create a sufficiently high peak power to "open" the saturable absorber system. By changing the cavity length at the proper speed, very high-power fluctuations can be induced. Once the instantaneous power in one of these fluctuations becomes sufficiently high, a slight Kerr lens is formed, the beam is narrowed and can pass unattenuated through the slit. This pulse is amplified and becomes the dominant pulse that will form the mode-locked output.

Normally, in a laser such as titanium:sapphire, only one or two longitudinal modes operate simultaneously. This is due to the fact that all atoms within the lasing medium are considered to be equivalent and are capable of emitting light over a range of frequencies and will emit at the same frequency as the stimulating light. Therefore, the earliest light to reach high intensity through the amplification process will establish the frequency for subsequent light. No atoms will remain in their upper state to amplify light at another frequency. In reality, two modes can operate simultaneously due to a phenomenon known as spatial hole burning that will not be covered here.

From the discussion above, the random fluctuations caused by even two modes do not cause very high instantaneous powers. A prerequisite for high-intensity fluctuations is that the laser be encouraged to operate simultaneously with as many longitudinal modes as possible. Of all the longitudinal modes that can lase, a few are more likely than others. This is due to the fact that any wavelength-selecting element will cause more losses on either side of the selected wavelength. As the wavelength selector (in the case or the Mira Optima, the BRF) is changed, some modes are discouraged and others are encouraged. Alternately, the modes themselves can be shifted in wavelength by changing the cavity length, so a different set of wavelengths satisfy the "integral half waves between reflectors" criterion. If the cavity length is changed rapidly enough, the freshly discouraged modes (previously oscillating modes) will die out, leaving atoms available for the new modes. There will be a period during which both can be lasing simultaneously. We have therefore created a transient condition under which the output of the laser contains more longitudinal modes than normally possible.

Once a larger number of modes are lasing, peak intensities are produced to initiate Kerr lens formation and the mode-locking process begins. An additional nonlinear process, called self-phase modulation (SPM), is initiated once these higher intensities are approached. SPM creates additional modes adjacent to the main pulse that result in an even more intense pulse and further reinforces the Kerr lensing process.

It is important to mention that once mode-locking starts, it will continue without the need of the starting mechanism. Thus, the rapid length variation is then halted.

The length of the cavity is changed, not by increasing the distance between the mirrors, but by changing the angle of a glass plate through which the beam must travel. As the angle is changed, more glass is traversed, and since light travels slower in glass than in air, it is entirely equivalent to increasing the distance between the mirrors. Both increase the time necessary to traverse the distance between the mirrors.

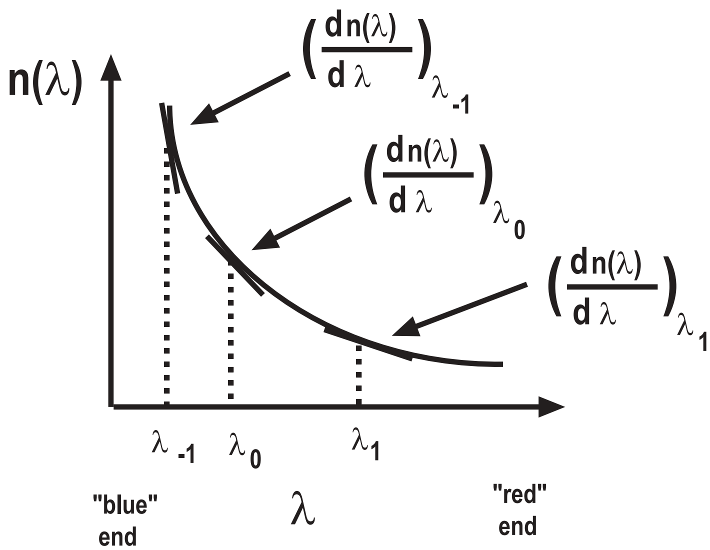
Transmission of Ultrashort Pulses of Light Through Glass

Group Velocity Dispersion

The wavelength of an ultrashort pulse of light cannot be determined precisely because it is formed by the sum of a distribution of wavelengths on either side of the center wavelength. The width of the distribution is inversely proportional to the length of the pulse. Moreover, in order to produce a short pulse of light from the distribution, the timing or phase between each component wavelength must be precisely correct, or the pulse will not be as short as it could be. It is easily demonstrated that an ultrashort pulse will lengthen after it has passed through glass. This is due to the fact that in all normal materials, the index of refraction and therefore the speed of light depends nonlinearly on the wavelength.

Figure 7-3 shows a hypothetical dispersion curve; i.e., a graph of refractive index (n) versus wavelength (λ) with a shape typical of many common materials that are transparent in the optical spectrum. The shape is typical in the sense that the index decreases monotonically with increasing wavelength while maintaining a gradual upward curvature. This is often referred to as "normal dispersion", whereas a material with a downward curvature is referred to as having "anomalous dispersion". At a given wavelength, the refractive index $n(\lambda)$ determines the phase velocity or the velocity of a single mode, a monochromatic wave. The slope of the refractive index curve, $\frac{dn(\lambda)}{d\lambda}$, determines the group velocity and thus defines the velocity of a wave packet (short light pulse) with a central wavelength λ. The second derivative of the curve, $\frac{d^2n(\lambda)}{d\lambda^2}$, determines the group velocity dispersion, which governs the rate at which the frequency components of a wave packet change their relative

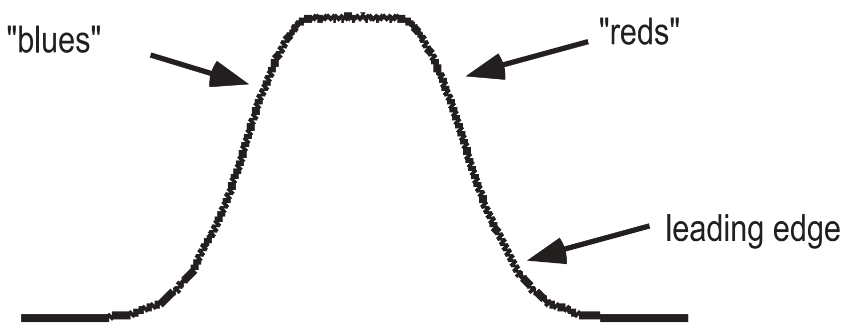
phases. Group velocity dispersion causes temporal reshaping of wave packets—this can be a broadening or a shortening shape change depending upon the initial conditions (chirp) of the wave packet spectrum. The term “chirp” means that the frequency of the packet is changing with time as in the chirping of a bird. Referring to Figure 7-4, we see that a pulse is said to be “positively chirped” if its instantaneous frequency increases from leading edge to trailing edge; i.e., the redder components lead the bluer components. This is the type of chirp that is normally imparted to a pulse after traversing “normal” materials with an upward curvature such as that depicted in Figure 7-3. Its blue spectral components are retarded with respect to the red, creating a systematic variation of phase with respect to wavelength. Similarly, a pulse is said to be “negatively chirped” if its red spectral components have been retarded with respect to the blue as seen in Figure 7-4.



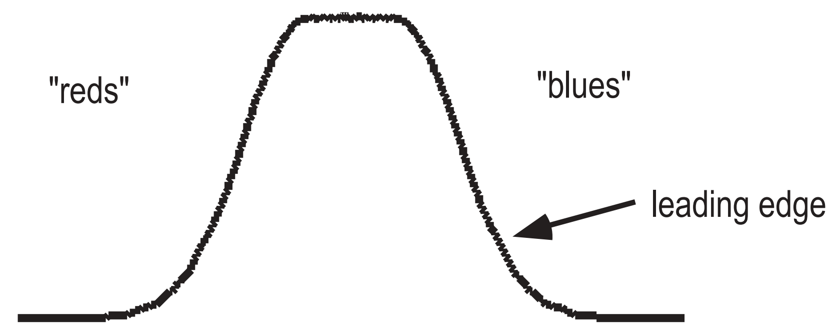
The curvature and hence GVD is determined by the 2nd derivative of the dispersion relation.

$$\frac{d^2 n(\lambda)}{d\lambda^2} \propto \text{"Group Velocity Dispersion"}$$

Figure 7-3. Group Velocity Dispersion Derivative



B. POSITIVE CHIRP — RED FREQUENCY COMPONENTS LEAD THE BLUES
(RESULTS FROM +GVD)



A. NEGATIVE CHIRP — BLUE FREQUENCY COMPONENTS LEAD THE REDS
(RESULTS FROM –GVD)

Figure 7-4. Group Velocity Dispersion

Self Phase Modulation

In addition to the phenomena already described, pulses in ultrafast lasers are also affected by self-phase modulation (SPM). Due to the optical Kerr effect, intense light pulses propagating through dense media create a local index of refraction that is dependent on the light field intensity. Therefore, the leading and trailing edges of the pulse will cause less change in the index than the center where the intensity is highest. This will subsequently cause parts of the pulse to move faster, thus altering the pulse shape.

Frequency components propagating through the material are thus phase-shifted differently, depending upon where they occur in the pulse. This phenomena actually generates new frequencies (or eliminates old ones depending upon the initial conditions). These frequency components are inherently chirped and can broaden the pulse unless the chirp is compensated. It can be shown that chirp which results from SPM has the same sign (positive) of the chirp introduced through normal material GVD.

Dispersion Compensation

Because of self-phase modulation and the GVD from the many dispersive elements within the laser cavity, some method must be employed to allow the slow frequencies or wavelengths to catch up with the faster ones. Each time it traverses the cavity, the circulating pulse receives a slight chirp from the dispersive elements it encounters. Without compensation, the cumulative effect of even a very small chirp per round-trip would create broadening and pulse substructure. We thus require an element or system of elements that has negative GVD; that is, the relationship between wavelength and speed or index must be the reverse of what it is in a normal material. In principle, negative chirps could be introduced by propagating the pulse through a material at a wavelength in which the curvature of the index curve goes downward—but in practice, this is not very practical. To accomplish this with some variability in the magnitude of the desired compensation, some type of special optical system must be constructed.

In the previous paragraph on group velocity dispersion, the concept of GVD was introduced within the context of index of refraction. It was noted that the existence of a finite second derivative of the index with respect to the wavelength was required in order to create GVD. In fact, this description does not only apply to simple material dispersion curves, but can also be generalized to any optical system by realizing that a more general description of GVD requires the existence of a finite second derivative of the optical pathlength with respect to wavelength.

For a given wavelength and a given optical system, one can express the phase evolution of the light wave traveling through the system by taking into account all of the effects that occur along the optical path, including refraction at surfaces. A pathlength curve, analogous to that shown in Figure 7-3, can be constructed for any complex optical structure having wavelength-dependent beam paths. Therefore, group velocity dispersion can be regarded as a property of an optical construction.

There are two common optical configurations that can introduce a negative chirp. Which optical configuration that is used depends on the bandwidth of the pulse and the amount of negative chirp that needs to be introduced. The optical system used in the femtosecond version of the Mira Optima consists of a pair of prisms separated by a distance oriented in a specific way with respect to each other. The optical system used in the picosecond version of the Mira Optima is a Gires-Tournois Interferometer (GTI).

It can easily be shown that the net GVD of a prism pair can be made negative by proper choice of prism material (and its index properties) and the distance between the prisms. The GVD compensation scheme operates as follows (refer to Figure 7-5): A pulse is formed

and chirped by self-phase modulation in the titanium:sapphire crystal and by GVD in the various intracavity components in the laser such as the beamsplitters, BRF etc. The chirped pulse enters prism 1. Since prisms bend or refract different wavelengths into different angles, the beam spreads as it heads for the second prism. The blue components are bent more severely than the red ones, thus creating the possibility of wavelength-dependent path lengths for the various rays. The longer wavelength components (red) travel a shorter geometrical path as compared to the shorter wavelength components (blue). But, because the velocity of the light is significantly reduced as it travels through glass (the prisms), the optical path length of the red components is actually *longer* than that of the blue components since they spend more time in the prisms. So, this system behaves just oppositely to most materials. The GVD of this system is said to be negative, because the blue part of the pulse travels through the system faster than the red. The magnitude of the GVD compensation can be easily controlled over a range by prism glass path adjustment (see below); the tuning range is sufficient to allow the "net cavity GVD" to be tuned through zero.

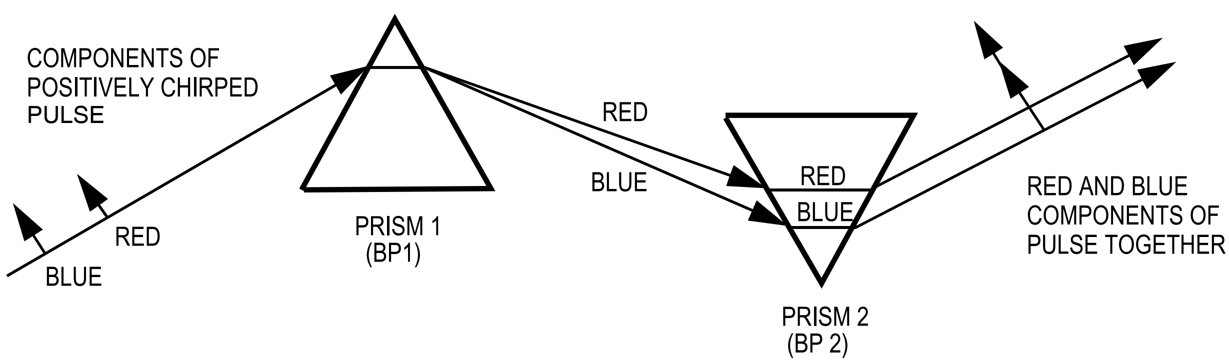


Figure 7-5. GVD Compensation

Finally, in the Mira Optima, a mirror is placed after the second prism to retroreflect the beam back through the pair and spatially re-combine the beam, thus completing the GVD compensation. The figure shows one pass for simplicity.

Changing GVD

The total round trip chirp of the system is the sum of the chirps arising from SPM, positive material GVD and negative GVD of the compensator. A simple way to adjust the GVD component of the chirp is to change the amount of glass within the cavity. Translating

one of the prisms in the compensator is a very convenient way of inserting more or less glass. Thus the proper GVD can be adjusted very simply.

The Formation of Final Pulse Width

In practice, the pulse-forming mechanism is dynamic in nature. This is due to the fact that, although the prisms and optical material within the cavity define the total dispersion within the cavity, self phase modulation depends on the intensity of the pulse. As the pulse gets shorter, its intensity becomes higher because all of the energy in the long pulse is now emitted over a shorter interval. There is therefore more self phase modulation and hence more broadening.

Finally, the pulse reaches a stable width and pulse amplitude. This process of establishing an equilibrium pulse, which upon one trip through the cavity remains unchanged, is related to a nonlinear pulse formation process called Soliton-formation. The periodically reforming wave is referred to as a Soliton. Soliton-like pulse formation has many attractive features. Most importantly, if the pulse becomes more intense for some reason, the increased self-phase modulation will cause the pulse to broaden, distributing the pulse energy over a longer period of time and thus reducing the pulse intensity. The laser, therefore, is self-regulating and results in an extremely stable output.

The Effect of GVD on Stability and Pulse Width

Stable pulses can be formed only when the chirping caused by SPM plus material GVD cancels the negative GVD introduced by the prism pair. Under these conditions, the red and blue wavelength components of the pulse do not change their relative positions within the pulse over one complete round trip through the cavity. As the amount of positive GVD is changed by inserting or removing material from the cavity, the pulse changes width. This must be true because adding more material GVD changes the balance between material positive GVD, negative prism pair GVD, and chirp caused by SPM. Only SPM can be changed dynamically. In order for the total GVD to be the same, the pulse peak power must change. This changes its width so that the energy per pulse is the same.

Following is the relationship governing soliton pulse shaping in homogeneous media (such as an optical fiber).

Equation [7-1]. Relationship Governing Soliton Pulse Shaping

$$\tau^2 = \frac{\beta}{\lambda P}$$

β = Sum of positive material GVD and prism pair negative GVD

γ = SPM coefficient

τ = pulse width

P = peak power in pulse

P is regulated by the soliton formation mechanism and can be considered constant for a given pump power, output coupler and wavelength.

γ is related to the nonlinear properties of titanium:sapphire and is also a constant. It represents the nonlinear phase shift in titanium:sapphire per unit length per unit power.

β can be varied in the Mira Optima by translating BP1 through the beam. With this scheme, the total β increases from negative towards zero to slightly positive.

Strictly speaking, the equation above does not apply to an inhomogeneous medium (such as a laser cavity) in which the sources of SPM, and negative and positive GVD are physically separated but it nonetheless offers considerable guidance in scaling the laser behavior and understanding the phenomena that pertain in the Mira Optima cavity. This is the reason the pulse formation is referred to as "soliton-like".

Therefore, the equation above indicates that as more negative GVD is inserted in the cavity, the pulse shortens; i.e., the magnitude of β decreases.

A typical relationship between the second prism position as indicated on the prism translation stage micrometer and the resulting pulsewidth at 800 nm is shown in Figure 7-6.

The pulse formation is stable only when the chirps from SPM, material GVD and prism pair negative GVD satisfy the above equation. Only under these conditions will the pulse maintain its shape in one round trip through the cavity. Because the chirp from SPM is equivalent to that from positive GVD (to first order), the glass in the system plus the negative GVD of the prism pair must be less than zero.

Mira Optima is designed to allow the material GVD plus the prism pair negative GVD to be varied total negative to just slightly total positive. High negative GVD accompanied by longer pulses can be obtained by translating one of the prisms so the beam strikes as close to the prism tips as possible. Shorter pulses are obtained as the prism is translated further into the beam. As the pulse becomes narrower, a point will be reached beyond which further reduction of GVD (from negative towards positive) will cause pulse formation to stop.

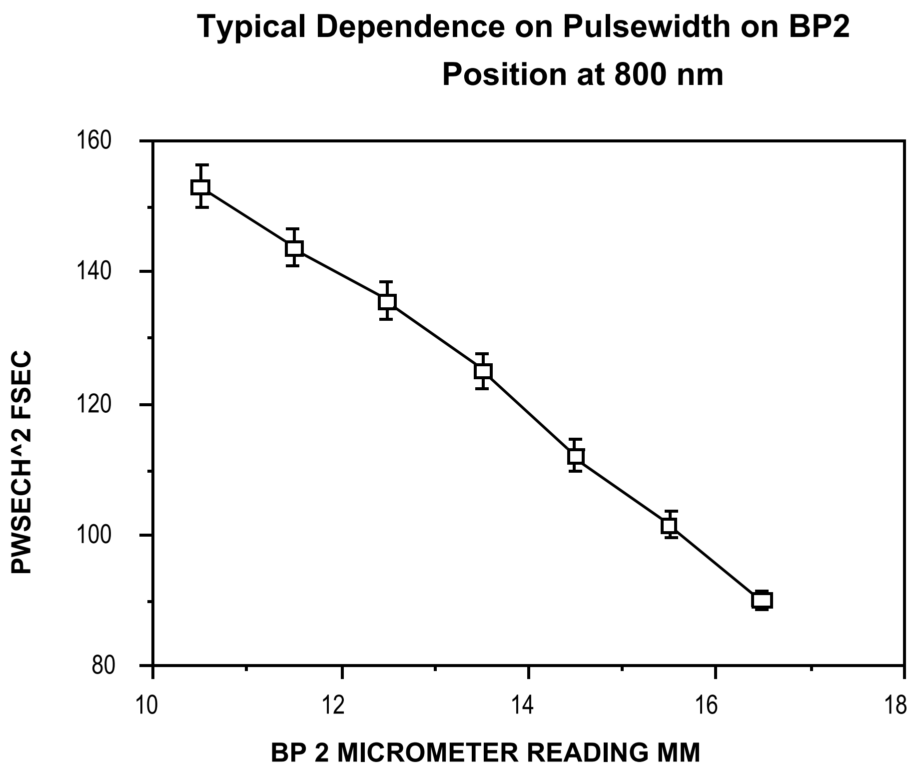


Figure 7-6. Pulse Width vs. BP2 Position

Tuning Mira Optima

As the BRF is rotated, two changes in the pulse will be observed

1. Change in pulsewidth
2. Change in spectral width

Both of these changes are due to the same phenomenon. An examination of the prism compensator Figure 7-5 reveals that as the wavelength changes, the angle of refraction from the first prism changes. This means that the center of the beam will strike the second prism in a different location. In particular, as the wavelength is shifted towards the red, or longer wavelength, the beam is refracted less. The beam therefore strikes the second prism further from the apex and therefore passes through more prism glass. Since the GVD is negative, more positive GVD causes a decrease in the absolute value of GVD towards zero. According to Equation [1], this results in a decrease in pulsewidth.

In order to maintain the same pulsewidth as the wavelength is changed, it is only necessary to translate the prism to "follow" the beam. Figure 7-7 shows the required rotation of BP2 control in order to maintain constant pulsewidth as the wavelength is changed.

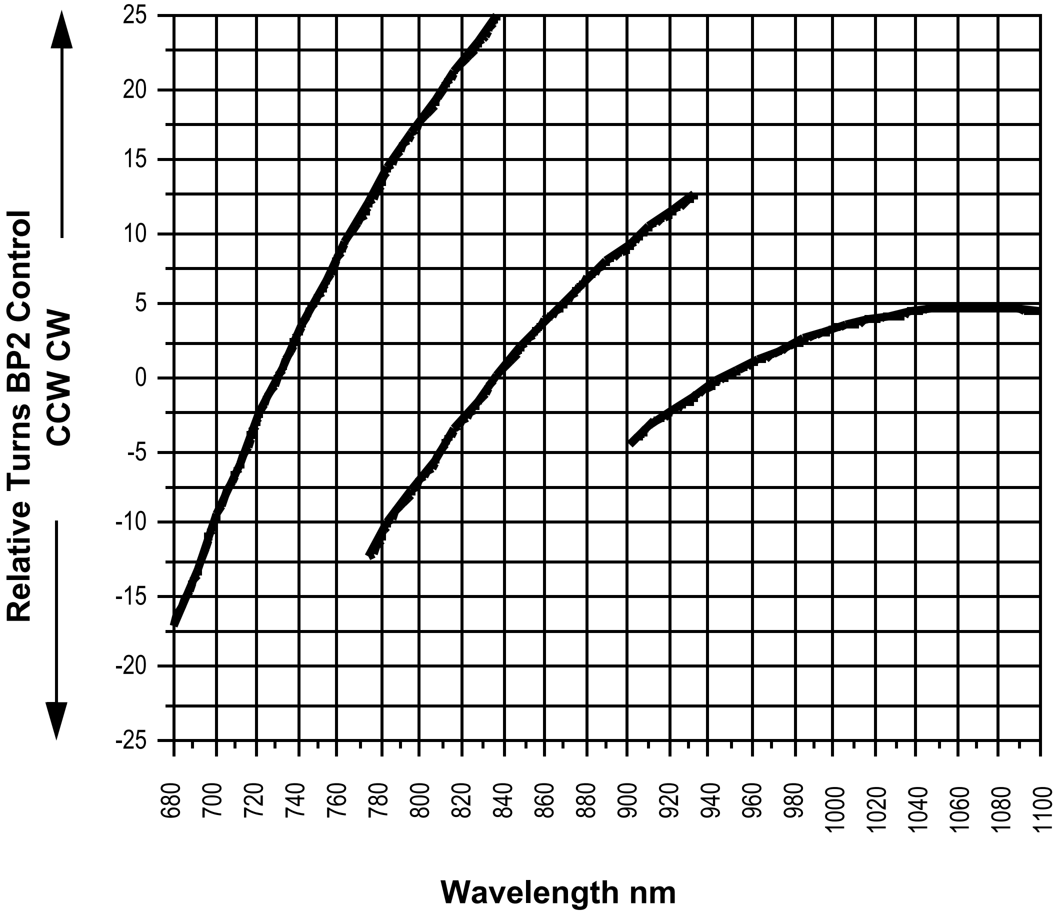


Figure 7-7. BP2 Control as Function of Wavelength to Maintain Constant Pulsewidth Short, Mid, & Long Wave Mirror Sets

Description of CW Detector

Because the saturable absorber cross-section in the Mira Optima system may be varied with slit width, it is necessary to indicate when the slit has eliminated the CW portion of the output mode. A scanning etalon with free spectral range less than the Mode-locked spectral width is employed. Even an extremely small CW component results in etalon fringes that are detected as a modulated transmitted power into the CW detector.

This detection system is sufficiently sensitive, such that if no CW power is indicated on the controller display, the average power in the CW component is less than 1%. Experimentally, this average level is below 1E–4, the ratio of peak power to average CW power at this level is 1E+9. The disappearance of the CW mode is abrupt; there is either an indication of CW on the controller or the CW component has been reduced to a very low level, as indicated above.

Factors Influencing Mode-locked Operation

Since SPM is dependent on intensity, stable mode-locked operation depends on maintaining the proper power inside the cavity. Therefore any problem that reduces the output power from its nominal value will compromise the ability of the system to produce stable pulses.

Alignment

If the system is not optimally aligned to obtain the nominal average power, the power within the cavity will be different that will effect the stability of performance. Both the pump beam and laser cavity mirrors must be optimally aligned. (Procedures for alignment and cleaning are covered in other chapters of this manual.)

Mode Quality of Pump Laser

If the transverse mode quality of the pump laser is not nominal, pumping efficiency will be compromised and laser power will be lost.

Differential Overlap

Another issue intimately related to the mode quality of the pump laser involves the overlap between the pumping laser beam and the intracavity beam inside the gain medium. In addition to the changing size at the slit, the formation of the Kerr Lens causes the intracavity beam to change size and shape inside the titanium:sapphire. With proper design, this effect can be utilized to produce differential gain in favor of mode-locked operation, thus enhancing the saturable absorption system. In the design of the Mira Optima, this size/shape change between CW and mode-locked operation has been optimized for the nominal pump volume created by standard Coherent pump sources. Substantial deviation from the standard pump volume criteria will generally lead to unpredictable results.

Pump Power

System output power stability and starting reliability may be compromised if pump power is varied more than 20% from nominal value. Coherent strongly recommends that the pump power used during the factory alignment be maintained unless Coherent advises otherwise.

Contaminated Optics

Any loss within the laser reduces the power and affects the pulse stability.

Slit Width

If the slit is too wide or too narrow, stable pulses will not be formed. If the slit is too wide, both mode-locked and CW beam diameters will pass through. Refer to Figure 7-1. Any CW component of the output is an indication that the slit is too wide.

Also, if the slit width is too wide, multiple pulsing can be observed. Multiple pulsing is indicated by any of the following:

1. Modified waveform seen from the output of the fast photo-diode.
2. Mode-locking rep rate at 152 MHz.
3. Multiple pulses seen on the autocorrelator.
4. Abnormally narrow bandwidth.
5. Abnormally high mode-locked power with no indication of increased peak power such as increased signal height on auto-correlator or other experimental nonlinear outputs. In this case, the pulse as seen on fast photodiode will have two distinct heights as the slit is closed. The lower value is the correct one.

If the slit is too narrow, relaxation oscillations will often modulate the output power that can be seen on an oscilloscope as erratic pulse intensity as well as in the autocorrelator as a modulation on the pulse shape. This condition is often referred to as Q-Switching.

Beam Clipping

It is possible through mechanical misalignment that the beam may not pass clearly through the various intracavity apertures. This results in losses that reduce the intracavity power. Because the beam moves as the wavelength is changed, the beam must strike all mirrors far from the edges.

Titanium:sapphire Temperature

There is a weak dependence of output power on titanium:sapphire temperature. Elevated temperatures reduce power and make pulse formation less stable. To minimize the total variation in output power, Coherent recommends that water temperature be regulated to within ±0.1 degree.

Purge Gases

The Mira Optima packaging allows the intracavity space be purged with water-free gas. *Coherent recommends when operating the laser at above 890 nm, a dry nitrogen purge be maintained.*

In addition, between 920 nm and 980 nm, strong water absorption interferes with the operation of the system. A high-velocity purge of the package for several hours is sufficient to bring the humidity to near zero. In this tuning region in particular, maintenance of the relative humidity must remain below 5%.

Other weaker absorption lines appear in the vicinity of 780 nm and 850 nm, but under most conditions it is not necessary to purge the cavity at these wavelengths.

Propagation of Ultrashort Pulses Through Optical Materials

In any experimental arrangement, the fact that ultrashort pulses broaden when passing through any glass must be taken into consideration. In general, the shorter the initial pulse, the greater the broadening. In other words, the broadening experienced by a picosecond pulse is significantly less than a femtosecond pulse. Also, many types of glass have significantly different dispersion properties. Figure 7-8 shows the effect of several common types of glass on the pulsewidth of a 100 fs pulse. It can be seen that fused silica and BK7 are relatively benign whereas a dense glass such as SF10 should certainly be avoided.

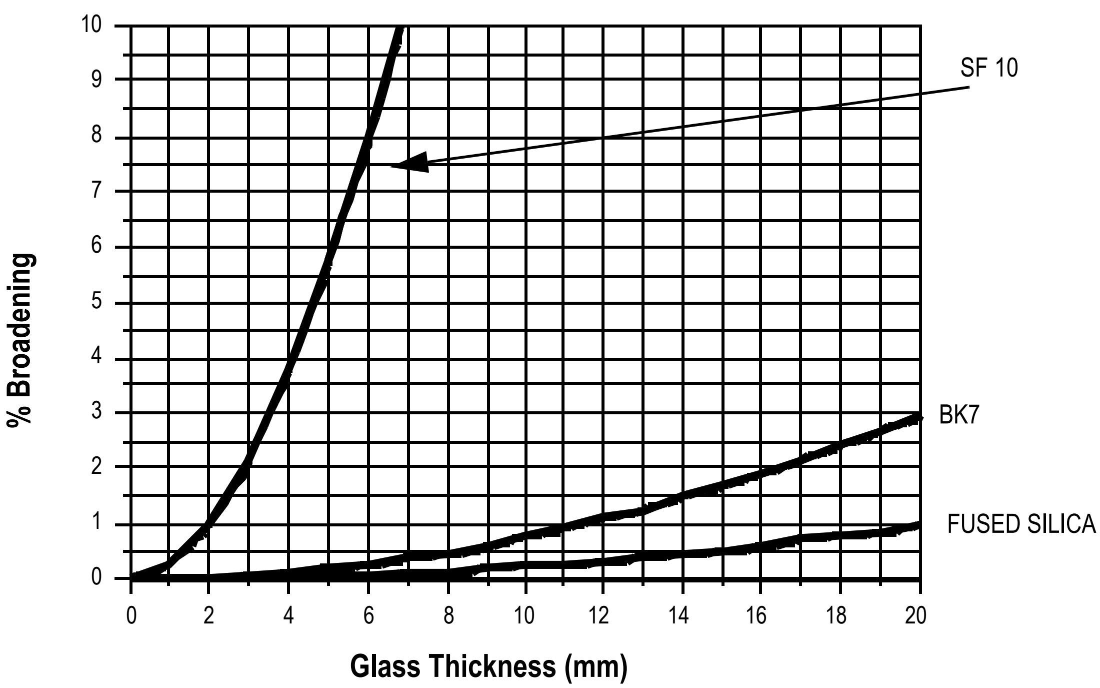


Figure 7-8. Comparison of Pulse Broadening in Fused Silica, BK7, and SF10 for 100 fs Pulse

Autocorrelation

A real-time autocorrelator is a recommended alignment and maintenance tool for the Mira Optima. In Chapter Four, Daily Operation, assume that an autocorrelator is available at all times to monitor the pulse characteristics. The following sections describe the operating principles of a rotating mirror autocorrelator.

Optical Schematic Overview

The optical schematic of a rotating mirror autocorrelator is shown in Figure 7-9. The laser beam enters the input port and strikes the beam

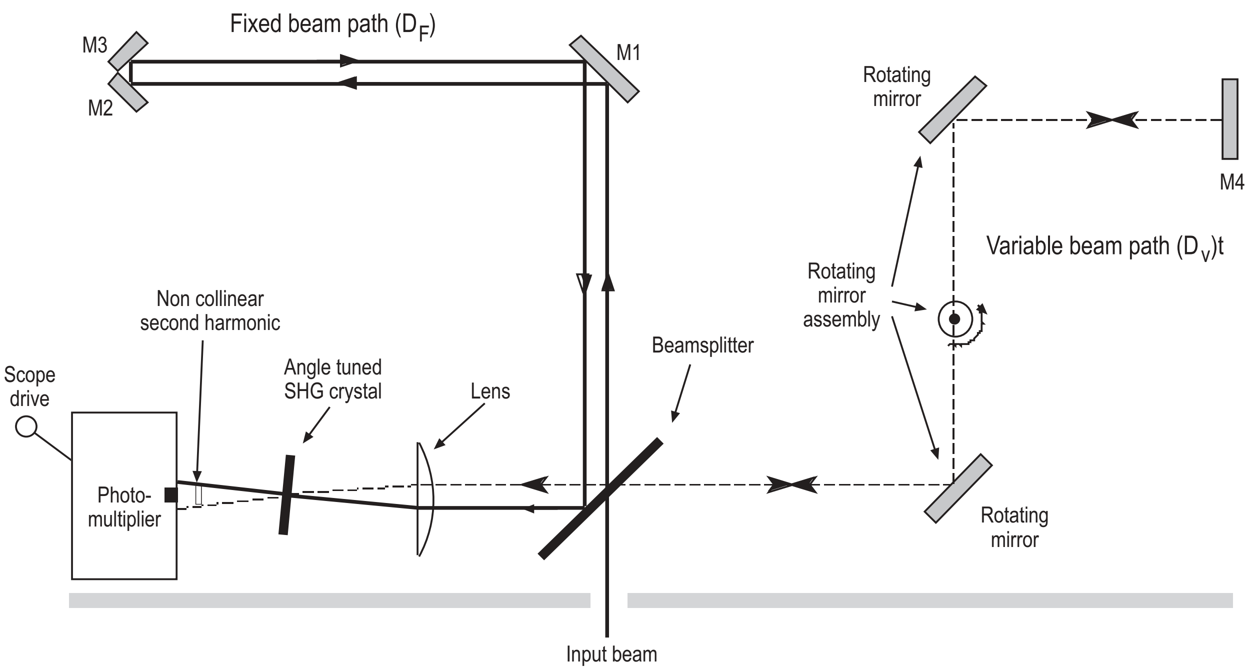


Figure 7-9. Autocorrelator Optical Schematic Diagram

splitter, forming two beams designated as "Fixed" and "Variable". The fixed beam path is defined by mirrors M1 through M3 and has a total distance D_F. The variable beam path includes mirror M4 and the spinning mirror assembly that creates a time-dependent beam distance $D_V(t)$. The two beams are parallel but slightly separated when they reach the lens, which refracts them along mutually converging paths that cross in the second harmonic crystal. An output second harmonic beam (at half the laser wavelength) appears after the crystal, traveling in a direction that bisects the angle between the two input beams. This beam contains the autocorrelation signal and is detected by the photomultiplier.

The Concept Of Autocorrelation

When a single pulse with envelope function $E(t)$ enters the autocorrelator, it is split by the beamsplitter into two identical copies. The one which follows the fixed path requires a time interval of $\frac{D_F}{c}$ to reach the lens, whereas the one that follows the variable path requires $\frac{D_V(t)}{c}$.

$E(t)$ has been converted to a signal of the form:

$$E\left(t-\frac{D_F}{c}\right)+E\left(t-\frac{D_V}{c}\right)= E(t)$$

at the lens. The two copies of the pulse travel to the SHG. In general, second harmonic generation produces an output proportional to the square of the input, or in this case.

Equation [7-2]. Square of the Envelope Function of the Signal in the Autocorrelator

$$E^2\left(t-\frac{D_F}{c}\right)+\left(E^2\left(t-\frac{D_V(t)}{c}\right)+E\left(t-\frac{D_F}{c}\right)E\left(t-\frac{D_V}{c}\right)\right)$$

The first term of Equation [7-2] represents a second harmonic pulse formed only from light that propagated along the fixed beam path, and the second term is the same quantity for the variable beam path. The third term, however, represents a pulse formed from a mixing of the light that traveled along the two different paths. Its magnitude depends on the path difference between the fixed and variable arms of the autocorrelator, as can be seen by substituting $t' = t-\frac{D_F}{c}$ into Equation [7-2] and rearranging the terms to produce:

Equation [7-3]. The Envolope Function Expressed as a Function of the Temporal Path Difference of the Two Arms

$$E^2(t')+E^2(t'-A(t))+E(t')E(t'-A(t))$$

where $A(t) = \frac{(D-D_V(t))}{c}$ is the time difference introduced by the autocorrelator between the fixed and variable copies of the pulse, changing over time according to the action of the spinning mirrors.

The photomultiplier tube (PMT) is much slower than the pulse envelope function $E(t)$. The photomultiplier therefore integrates the light incident upon it and produces a signal $S(t)$ that is mathematically the integral of Equation [7-3].

Equation [7-4]. Response of the PMT to the Incident Light

$$S(t) = \int((E^2((t')+E^2t'-A(t))+E(t')E(t'-A(t)))dt'$$

The first two integrals are identical and are independent of the path difference $A(t)$. The third integral contains the pulse autocorrelation information that we wish to measure.

Background-Free Autocorrelation by Non-Collinear Phase Matching

While it is possible to obtain useful information from the signal represented by Equation [7-4], the first two integrals constitute a fixed background level that complicates the interpretation of observed data. These two integrals are effectively eliminated by the method of non-collinear phase matching in the SHG crystal. A simple theoretical understanding of this method can be gained from the momentum representation of the second harmonic process, in which there is a three-wave interaction satisfying the following conservation requirement.

Equation [7-5]. The conservation of momentum for a Second Harmonic process

$$k_F + k_V = k_{SHG}$$

The *k*'s are vector quantities associated with the fixed, variable, and second harmonic light fields, respectively. The direction of each *k* is the direction of beam propagation and the magnitude of each *k* is inversely proportional to the wavelength of the light. The vector equation (Equation [7-5]) can be represented geometrically for the case of non-collinear phase matching by Figure 7-10, where it is assumed that k_F and k_V are identical in magnitude but slightly different in direction. The figure shows that the direction of k_{SHG} must fall halfway between the fixed and variable beam directions. Thus the non-collinearly phase-matched pulse, the third term in Equation [7-5], can be identified and selected by its propagation direction. The photomultiplier is positioned behind a small entrance slit that passes predominantly the non-collinear beam, thus measuring a signal produced by only the third term in Equation [7-4]. This is often called background-free autocorrelation.

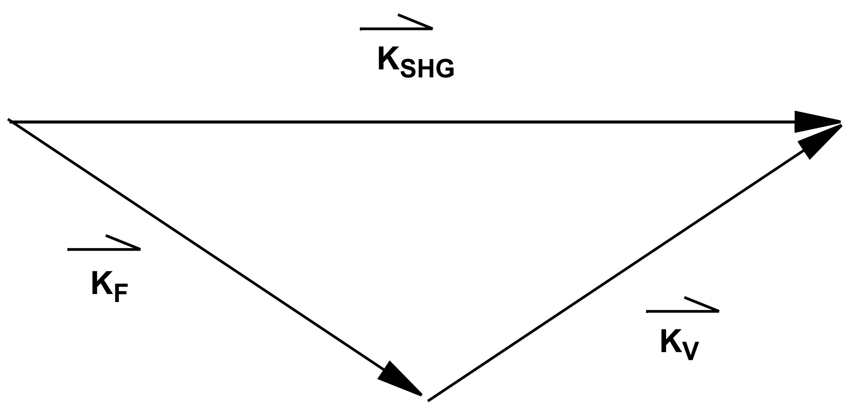


Figure 7-10. Non-collinear Phase Matching

Calibration and Real-time Display

The below expression for $A(t)$ is a reasonable approximation for the changes that occur in the variable delay path as a function of time.

$$A(t) = t_0 + mt$$

Deviations from the straight line approximation behavior can be evaluated by calibrating the autocorrelator at several different positions within its total scan range. For measurement of Mira Optima pulses such deviations are generally not significant.

Equation [7-6]. Respone of the PMT Expressed as a Function of the Pulse Time Delay

$$S(t'') = \int E(t')E(t' - t_0 + t'')dt'$$

The substitution $t'' = mt$, relating pulse delay time t'' to real time t, has been made. This is the exact expression for the pulse autocorrelation function (except for the constant offset t_O). The variable t'' is the pulse time delay introduced by the spinning mirrors. It is related to real time by the constant factor m that is the calibration factor for the autocorrelator.

When making an autocorrelation measurement on a high repetition rate laser such as the Mira Optima, pulses are continually incident on the autocorrelator. The photomultiplier signal represents the instantaneous value of $S(t'')$, that varies over time as the mirrors spin. On most autocorrelators, the photomultiplier output is then sent to an oscilloscope (some autocorrelators have a built-in display) to provide a real-time display of the autocorrelation function. The calibration factor m must be applied to the real-time display to convert real time t to pulse delay time t''.

A typical calibration factor might be 30 ps/ms, indicating that a 30 ps pulse autocorrelation width would produce an oscilloscope trace with a FWHM of 1 ms. A Mira Optima pulse with an autocorrelation width of 300 fs would therefore produce an oscilloscope trace with a FWHM of 10 µs.

Time Resolution

The time resolution of the autocorrelator is related to the time constant of the photomultiplier. An estimated time resolution is obtained by multiplying this time constant by the calibration factor.

Interpretation of Autocorrelation Traces

An autocorrelation trace is an indirect measure of a pulse shape and in principle cannot reveal the exact shape of $E(t)$. For example, $S(t'')$ in Equation [7-6] is always symmetrical about the position t''-t_O; autocorrelation functions are always symmetrical around their peak. Information about asymmetries in $E(t)$ is therefore unavailable from a measurement of $S(t'')$.

As a tool for measuring pulse widths, autocorrelation techniques are limited by the fact that there is no general relationship between the width of $S(t'')$ and the width of $E(t)$. The ratio of FWHMs between $S(t'')$ and $E(t)$ can be calculated for model pulse shapes, but it is difficult to estimate the validity of the model for a given practical situation. Table 7-1 lists some common model pulse shapes and the corresponding FWHM ratio.

Autocorrelation traces for Mira Optima pulses suggest by their functional form that they are best described by a $sech^2$. Table 7-1 indicates that a factor of 0.648 should be applied to convert observed autocorrelation widths to actual pulse widths. While such a conversion may provide a useful insight into the detailed properties of the pulse, it should be done with an awareness of the assumptions and possible errors involved.

Table 7-1. Time-Bandwidth Products For Typical Model Pulse Shapes

FUNCTION	I (T)	T_P/T_{AC}	$\Delta N\ T_{AC}$	$\Delta N\ T_P$
Square	$I(t) = \begin{Bmatrix} 1;\lvert t\rvert \le \tau_p/2 \\ 0;\lvert t\rvert > \tau_p/2 \end{Bmatrix}$	1	1	1
Gaussian	$I(t) = \exp-\left[\frac{4(\ln 2)t^2}{\tau_p/2}\right]$	0.707	0.624	0.441
Hyperbolic secant	$I(t) = \mathrm{sech}^2\left(\frac{1.76t}{\tau_p}\right)$	0.648	0.486	0.315
Lorenzian	$I(t) = \frac{1}{1+\left(\frac{4t^2}{\tau_p^2}\right)}$	0.500	0.441	0.2206
Symmetric 2-sided exponential	$I(t) = \exp-2\left\lvert\frac{t(\ln 2)}{\tau_p}\right\rvert$	0.413	0.344	0.142

$\tau_p \equiv$ FWHM of intensity envelope function in seconds.
$\tau_{ac} \equiv$ FWHM of autocorrelation function of corresponding intensity envelope.
$\Delta\nu \equiv$ FWHM of power spectrum in units of Hertz.

Time-Bandwidth Product

Multiplying together the spectral bandwidth and the real temporal width produces the time-bandwidth product, that has a theoretical minimum value known as the transform limit. This chapter defines this terminology.

The time-dependent electric field $E(t)$ associated with any laser pulse at a fixed point in space can be written in general form as in Equation [7-7].

Equation [7-7]. Time-Dependent Electric Field

$$E(t) = A(t)\exp(-i\omega_0 t)$$

In this expression, $A(t)$ is the envelope function and ω_0 is the carrier frequency. Both $A(t)$ and $E(t)$ are complex functions. The frequency spectrum associated with the pulse $E(t)$ is given by the Fourier transform of $E(t)$, that is designated $E'(\omega)$.

Equation [7-8]. Fourier Transform of *E*(*t*)

$$E(\omega) = \left(\frac{1}{2\pi}\right)\int E(t)e^{-i\omega t}dt$$

Equation [7-9]. Fourier Transform of *E'*(*t*)

$$E'(\omega) = A'(\omega - \omega_0)$$

While the functions $A(t)$ and $A'(\omega)$ are complex, only the square of the field; i.e., $|E(t)|^2$ or $|E(\omega)|^2$, is generally observable due to the fact that photodetectors respond to intensity (power) and not to E-field. Thus information about the imaginary parts of $E(t)$ and $E'(\omega)$ that relate to phase variation within the pulse is not directly observable. However, this information can be inferred by comparing the pulse envelope intensity $|A(t)|^2$ with the power spectrum $|A(\omega)|^2$. A simple approach to this can be taken in cases where the envelope functions $A(t)$ and $A'(\omega)$ are smoothly varying. One can then define the intensity temporal width and the pulse bandwidth of the power spectrum as:

Equation [7-10]. Pulse Width (Seconds)

$$\tau_p = FWHM(|A(t)|)^2$$

Equation [7-11]. Bandwidth (Hz)

$$\Delta\nu = 2\pi FWHM(|A'(\omega)|)^2$$

FWHM denotes the full width at half maximum.

The observable quantities τ_p and $\Delta\nu$ determine the time-bandwidth product (T).

Equation [7-12]. Time-Bandwidth Product

$$\tau_p \times \Delta\nu = T$$

The time-bandwidth product is an easily measured characteristic of ultrafast pulses. It provides a useful estimate of pulse quality, since it achieves its minimum value when $A(t)$ is purely real and the pulse is fully phase coherent. For ultrafast pulses, however, interpretation of time-bandwidth product data suffers from the limitation that the pulse envelope function $|A(t)|^2$ can only be measured indirectly by means of autocorrelation techniques. It is possible to examine several model functions for $A(t)$ and to calculate the minimum time-bandwidth product for each model using Equation [7-7] through Equation [7-11]. This information is presented in Table 7-1.

Operator's Manual

Chapter Eight
Femtosecond to Picosecond Conversion

COHERENT

Introduction

The Mira Optima is sold in one of three different configurations.

- Mira Optima 900-F: sub-150 femtosecond pulses
- Mira Optima 900-P: sub-5 picosecond pulses
- Mira Optima 900-D: Configurable as either of the above.

This chapter details the conversion between the two pulse regimes available from the Mira Optima 900-D. At any time the Mira Optima 900-F can be field upgraded to the Mira Optima 900-D.

Femtosecond to Picosecond Conversion

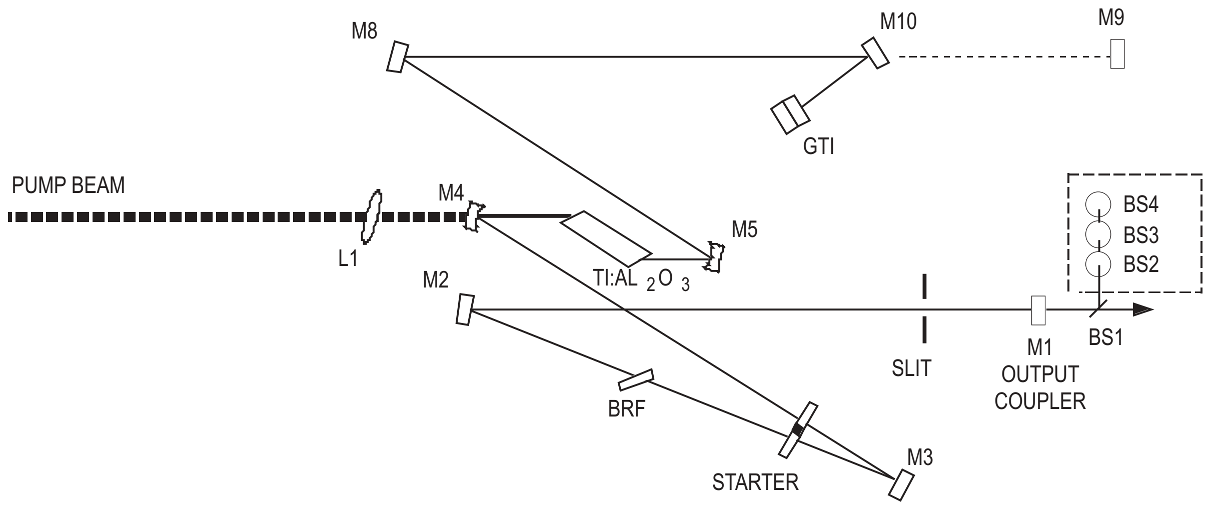
Conversion Summary

A summary of Mira Optima conversion from femtosecond to picosecond is listed below. The following paragraphs in this chapter contain detailed procedures for each process step listed below.

1. Remove BP1 from the beam path.
2. Remove the femtosecond output coupler (M1) and install the picosecond output coupler (M1).
3. Remove the femtosecond birefringent filter and install the picosecond birefringent filter.

BP1 Removal

1. Turn the BP1 micrometer clockwise (towards the lower reading) until it stops. This will translate the prism out of the beam path. Refer to the optical schematic Figure 8-1.
2. Verify that the birefringent filter is at the peak of the tuning curve. Refer to the tuning chart for the micrometer setting.
3. Open the slit assembly by rotating the slit width control clockwise.
4. Make small adjustments to the following controls to maximize the power on the control display. Adjust one control at a time and in the order listed.
    - P2 vertical and horizontal tilt angle controls.



Note: Solid lines represent picosecond operation.
Solid lines and dashes represent femtosecond operation.

Figure 8-1. Dual Cavity Configured for Femtosecond Operation

- Gires-Tournois Inferometer (GTI) vertical and horizontal tilt angle controls.

M1 Removal and Installation

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation. Set the controller CW/ML/β-Lock select switch to CW.
2. Remove the slit assembly by removing the 2 mounting screws (Figure 3-4).
3. Loosen the setscrew on top of the femtosecond output coupler M1 mount (Figure 3-4) and remove the optic by pushing the optic from the output side with the soft end of a cotton swab.
4. Neatly fold a sheet of lens tissue several times into a rectangular shape, ending with a folded edge that is 1/4 in. to 3/4 in. long, clamped with a hemostat, with approximately 1/8 in. of the tissue paper protruding from the side of the hemostat. To avoid scratching an optic, ensure that the hemostat is not clamped too close to the fold of the lens tissue.

While folding the tissue, be careful not to contaminate it with soiled or oily fingers in the place the tissue will eventually touch the optic to be cleaned.

5. Moisten the tissue with methanol or acetone. Two or three drops are sufficient for this purpose. Gently shake the hemostat to remove unwanted excess solvent.
6. Gently wipe one of the surfaces of the optic, then the other.
7. Using lens tissue to avoid touching the optical surfaces, install the new optic with the flat side facing up, and the arrow on the side of the optic pointing towards M2. Tighten the setscrew.
8. Turn the cooling water to the crystal on and unblock the pump laser beam.
9. Set the CW/ML/β-Lock switch on the controller to CW.
10. Hold the AUTO RANGE/PEAK RESET switch in the AUTO RANGE position for at least 2 seconds. This activates DC SUPPRESSION that is the most sensitive display on the controller.
11. Close and adjust the M2 alignment aperture so the fluorescent reflection from M3 is centered in the aperture. If necessary, block the retroreflection from M1 in order to cleanly see the fluorescence from M3
12. Locate the retro-reflection from M1 on the M2 aperture using an IR viewer.
13. Adjust the M1 horizontal and vertical tilt angle controls to center the retro-reflection in the aperture. In most cases, the system will begin to lase at this point.
14. Open the M2 aperture. Adjust M1 horizontal and vertical tilt angle controls to maximize the fluorescence (or laser power) on the controller display. If the Mira Optima does not lase after maximizing the fluorescence, repeat the alignment procedure or refer to Figure 4-1.
15. Maximize the output power using M1, the GTI, and P2 horizontal and vertical tilt angle controls respectively.
16. Re-install the slit assembly.
17. Open the slit assembly by rotating the slit width control fully clockwise.

Birefringent Filter Removal and Replacement

1. Block the pump laser beam. Turn the water to the crystal off to prevent condensation.
2. Set the controller CW/ML/β-Lock select switch to CW.
3. Remove the button head screw on the side of the Birefringent filter (BRF) assembly (Figure 3-7).

4. Remove the one-plate BRF and replace it with the three-plate BRF.
5. Turn the cooling water to the crystal on and unblock the pump laser beam
6. Close and adjust the M2 alignment aperture so it is centered over the M2 optic.
7. Use M3 vertical and horizontal tilt angle controls to center the fluorescence on the M2 aperture. If necessary, block the retroreflection from M1 in order to see the fluorescence from M3 cleanly. It may be necessary to reposition the BRF in the holder to avoid clipping of the beam.
8. To reposition the filter, loosen the BRF setscrew on the side of the outer ring of the BRF assembly and slide the inner ring until the beam no longer is clipping. Refer to Figure 3-7.
9. Use the M2 vertical and horizontal tilt-angle controls to position the fluorescence on to the center of the output coupler M1.
10. Locate the retro-reflection from M1 on the M2 aperture using an IR viewer.
11. Adjust the M1 horizontal and vertical tilt angle controls to center the retro-reflection in the aperture. In most cases, the system will begin to lase at this point.
12. Open the M2 aperture. Adjust M1 horizontal and vertical tilt angle controls to maximize the fluorescence (or laser power) on the controller display. If the Mira Optima does not lase after maximizing the fluorescence, repeat the alignment procedure or refer to Figure 4-1.
13. Maximize the output power using M1, the GTI, and P2 horizontal and vertical tilt angle controls respectively
14. Verify that the BRF is set to the proper tuning order. (Refer to the tuning chart for the micrometer setting or Figure 7-2 for correct filter orientation.)
15. Use an IR viewer to verify that the beam travels through the exact center of both butterfly arms vertically. If not, use the M3 vertical tilt angle control to adjust the vertical position on the butterfly arm closest to the slit. Use M4 vertical tilt angle control to adjust the vertical position on the butterfly arm closest to the side. For more information, refer to the paragraphs titled "Walking the Beam" on page 5-24 and "Walking the Beam" on page 8-7.

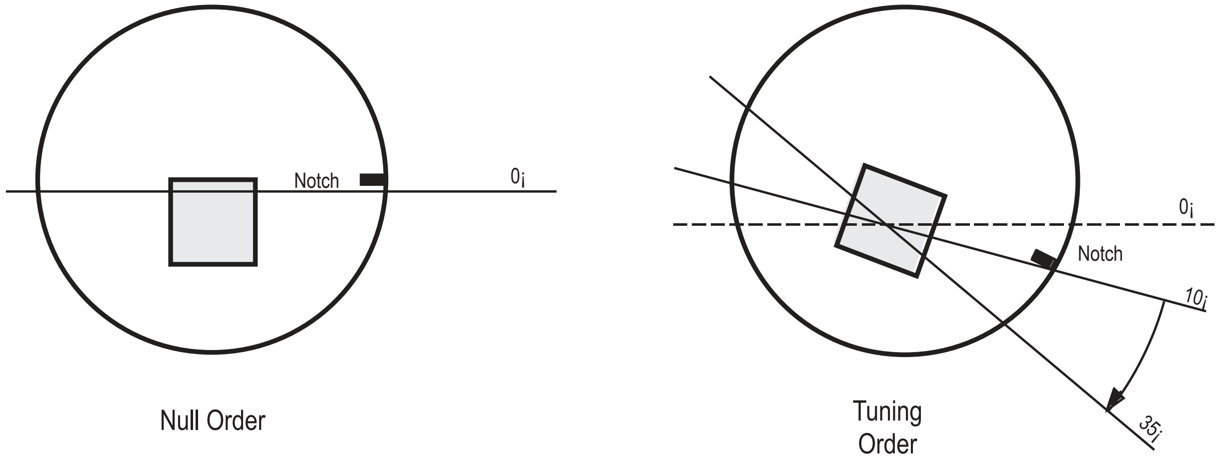


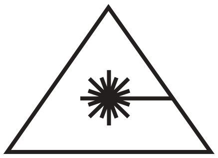
Figure 8-2. Birefringent Filter Tuning Order

Mode-locking

1. After the output power is maximized, reduce the slit width (turn the slit width control counterclockwise) until the output power is reduced approximately 50%.
2. Rotate the slit horizontal translation control for maximum output power. This centers the slit in the beam.
3. Repeat steps 1 and 2 to ensure slit is centered.
4. Set the CW/ML/β-Lock switch on the controller to the ML position.
5. Adjust the BRF slightly until the system mode-locks and optimize the slit width control for maximum power with zero CW content as viewed on the controller display.
   - The fast diode display from the Mira Optima laser head can be displayed on an oscilloscope to determine mode-locked operation (Figure 4-3).
   - After the system is mode-locked, switch the controller to β-Lock position and adjust the bias level for optimum pulse width while observing the pulse on an oscilloscope via an autocorrelator.

Walking the Beam

Walking the beam refers to the procedure to adjust the beam position between two adjacent mirrors such as M2 and M3. This procedure is executed while the system is lasing.



Safety glasses must used when performing this alignment as stray beams could be present that pose significant safety hazards.

Assume that the beam is not striking M2 in the center. Walk the beam as follows:

1. Adjust the M3 vertical tilt angle control to move the beam in the direction to center the beam on M2 until the power has decreased approximately 20%.
2. Adjust M2 vertical and horizontal tilt angle controls to recover power.
3. Repeat steps 1 and 2 until the position on M2 is satisfactory. Each repetition of steps 1 and 2 moves the beam about 0.25 to 0.5 mm.
4. Performing steps 1 through 3 affects the beam position on all optics on the same side of the crystal. Continue to walk the beam on all optics progressing to the end mirror as listed below.
   - M4, M3, M2, M1
   - M5, M8, M10, GTI

Operator's Manual

Appendix A
Installation with an Ion Pump Source

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Introduction

This chapter details the main differences between pumping with a Coherent Verdi Series DPSS pump source and a Coherent Ion pump source.

Ion Pump Laser Setup

1. Ensure the pump laser is turned off.
2. Carefully lift the pump laser and install a retaining/positioning block (supplied with the Mira Optima) under each foot. Ensure the correct blocks are used.
3. Position a power meter or beam block at the pump laser output aperture.
4. Turn on the pump laser in accordance with the pump laser operator's manual. Adjust the power for a low power output (approximately 100 mW). High and low power can be set in the controller memory of the pump laser to accomplish toggling between the two power settings.

   If using a Coherent Innova 300 series ion laser as a pump laser, install the low divergence output coupler P/N: 0163-321-00. The Innova series 200, 400, or Sabre ion lasers should automatically satisfy the low divergence requirement in their standard configurations.
5. The pump laser should also be operated in Light Regulation Mode (see pump laser operator's manual).

Ion Pump Beam Height and Leveling Adjustments

1. Position the alignment fixture #1 (Figure A-1) on the optical table approximately 6 in. (15 cm) in front the pump laser output aperture. Position the power meter or beam block behind the alignment fixture.
2. Adjust the front legs of the pump laser so that the pump beam is centered in the top hole of alignment fixture #1. Do this in accordance with the pump laser operator's manual. The pump laser must remain level (in the horizontal plane perpendicular to the beam axis) during this process.
3. Position alignment fixture #2 (Figure A-1) approximately 4 ft. (122 cm) in front the pump laser output aperture. Move the power meter or beam block behind the alignment fixture.
4. Adjust the rear feet of the pump laser so that the pump beam is centered in the top aperture of alignment fixture #2. The pump laser must remain level (in the horizontal plane perpendicular to the beam axis) during this process.

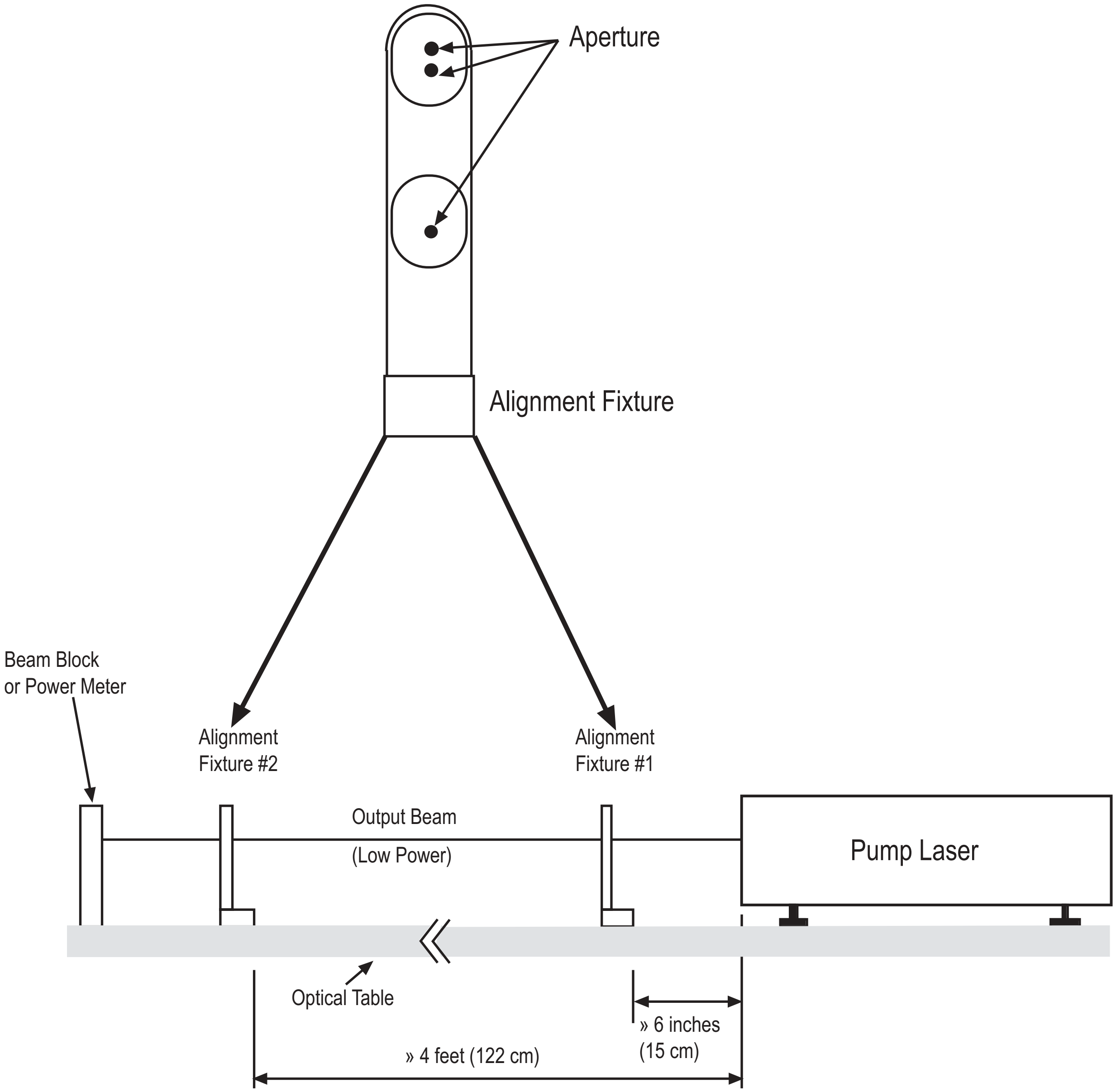

Figure A-1. Pump Laser Alignment

5. Repeat steps 1 through 4 until the output beam travels through the top apertures of both alignment fixtures without readjusting the pump laser. This positions the output beam parallel to the table top at 4.75 in. (12.06 cm) above the table. Leave the alignment fixtures in place.
6. Clamp down the pump laser head using the foot clamps provided in the Mira Optima accessory kit. Verify that the beam did not move and still travels correctly through both alignment fixtures. If the beam moved, repeat the pump beam height and leveling adjustments procedure.

7. Remove the alignment fixtures and proceed with the Mira Optima installation.

Main Cavity Alignment

The primary difference in the main cavity alignment if an Ion pump source is used is that instead of a single pump spot refracted from BP1, there are multiple pump spots, representative of the multi-line pumping of the Ion source. In this case, the below figure replace Figure 5-6.

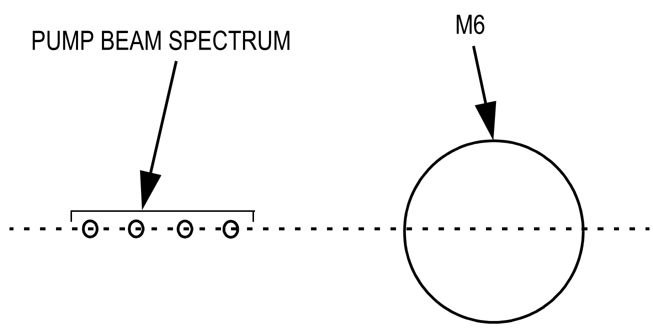

Figure A-2. Vertical Alignment of Pump Beam

Tuning Curves

This following pages contain typical tuning curves for Ion pumped Mira Optima systems with short wave (SW) or long wave (LW) optic sets. For information on tuning with a peak wave (PW) or extended long wave (ELW) optic set contact your local sales representative or call Coherent Advance Technical Sales at (800) 527-3786.

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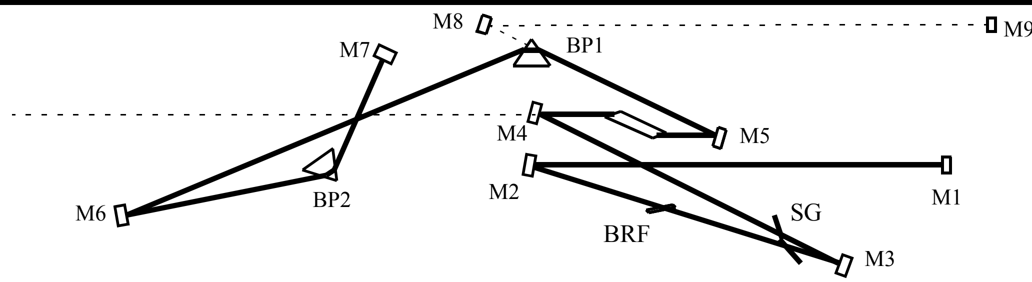
Mira ™ 900 - Femtosecond Titanium:Sapphire Laser Fact Sheet

SW Optic Set

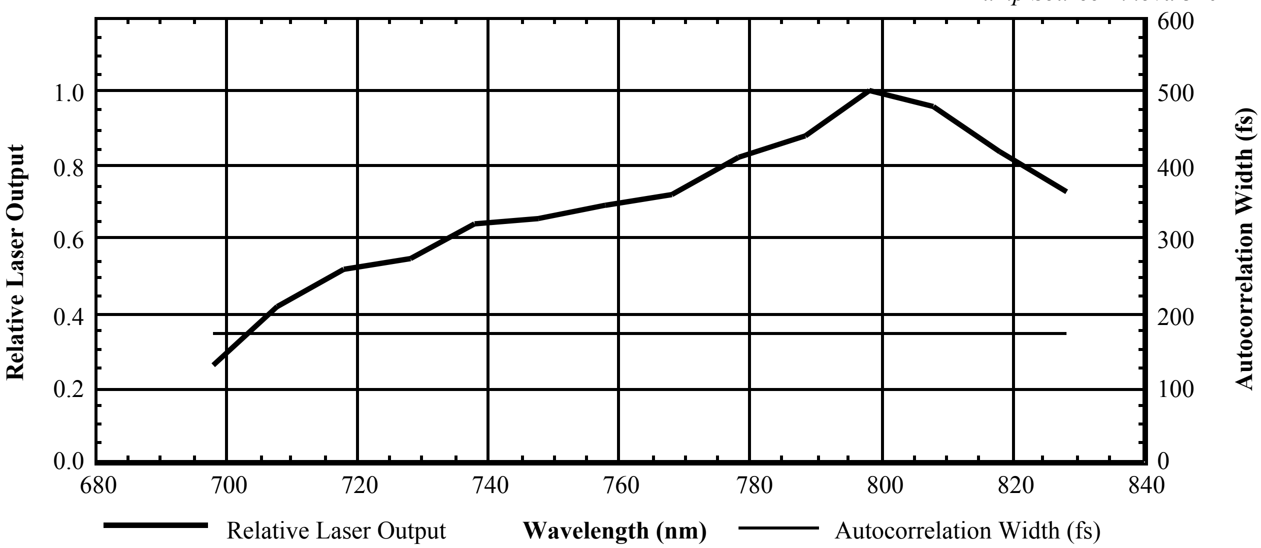
Optical Layout and Part Numbers



Mirror	Part Number	Radius	Description
P0 - P4	0161-712-00	Flat	Periscope Optics
L1	0163-052-00		Focusing Lens
M1	0163-057-00	Flat	Output Coupler
M2,M3	0158-791-09	Flat	High Reflector
M4	0163-048-00	10.0 cm	High Reflector
Xtal	0163-146-00		Ti:Saph Crystal
M5	0163-050-00	10.0 cm	High Reflector
M8, M9	0158-791-09	Flat	High Reflector
M6, M7	0163-049-00	Flat	High Reflector
BP1, BP2	0163-141-00		Prism Assembly
SG	0163-147-00		Starter Galvo Assembly
BRF	0162-692-00		Birefringent Filter

Ti:Sapphire Tuning Curve — 8 WATT PUMP — Non-Specified * See Note

Pump Source Innova 310



**The maximum peak output power achieved in the Mira 900-F configuration by Coherent personnel is 1300 mW*

Specifications:

Pump Power 8.0 Watts @ Multiline

Average Output Power:	500 mW	Femtosecond Tuning Range:	720 -810 nm
Autocorrelation Width:	200 fs	Beam Diameter at the Output Coupler:	0.8 mm ± 0.1
Peak Power [calculated(sech^2)]:	50 kW	Divergence (Full Angle):	1.5 mRad ± 0.2
Noise [rms measured in 10 Hz - 2MHz]:	< 2.0%	Polarization:	Horizontal
Mode:	TEM_{00}	Repetition Rate:	76 MHz

Notes:

1. Specifications only apply with Coherent pump lasers equipped with PowerTrack™ active stabilization.

2. When operating the laser between 759 - 766 nm the cavity must be purged with N_2 to improve overall performance.

Rev F. 5/92

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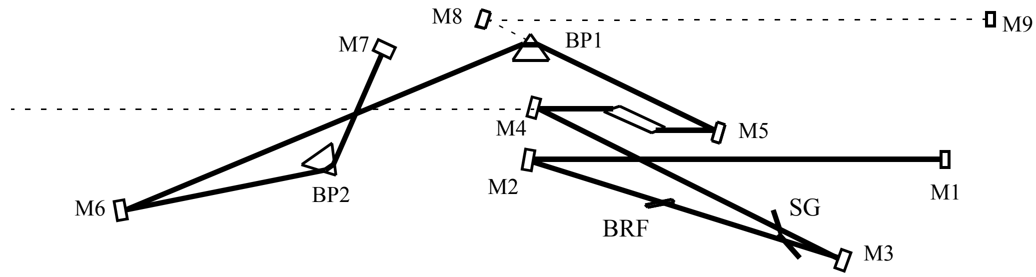
Mira ™ 900 - Femtosecond Titanium:Sapphire Laser Fact Sheet

LW Optic Set

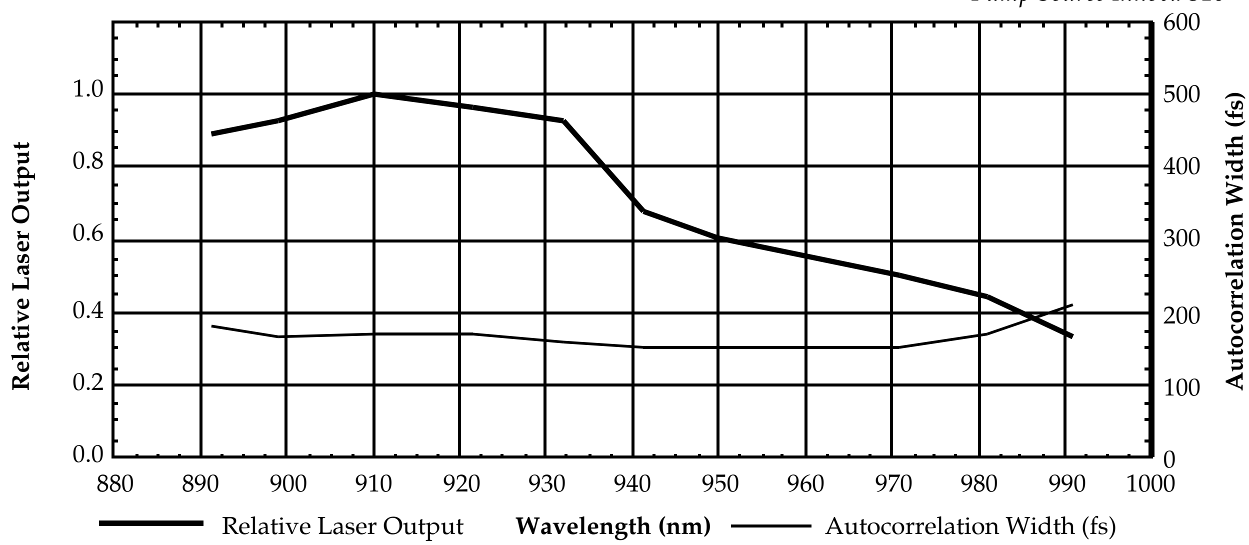
Optical Layout and Part Numbers



Mirror	Part Number	Radius	Description	Mirror	Part Number	Radius	Description
P0 - P4	0161-712-00	Flat	Periscope Optics	M5	0163-050-03	10.0 cm	High Reflector
L1	0163-052-00		Focusing Lens	M8, M9	0158-791-14	Flat	High Reflector
M1	0163-059-00	Flat	Output Coupler	M6, M7	0163-049-03	Flat	High Reflector
M2,M3	0158-791-14	Flat	High Reflector	BP1, BP2	0163-141-00		Prism Assembly
M4	0163-048-03	10.0 cm	High Reflector	SG	0163-147-00		Starter Galvo Assembly
Xtal	0163-146-00		Ti:Saph Crystal	BRF	0162-692-00		Birefringent Filter

Ti:Sapphire Tuning Curve | 8 WATT PUMP | Non-Specified * See Note

Pump Source Innova 310



**The maximum peak output power achieved in the Mira 900-F configuration by Coherent personnel is 550 mW*

Specifications:

Pump Power 8.0 Watts @ Multiline

Average Output Power:	270 mW	Femtosecond Tuning Range:	890 - 990 nm
Autocorrelation Width:	200 fs	Beam Diameter at the Output Coupler:	0.8 mm ± 0.1
Peak Power [calculated(sech^2)]:	27 kW	Divergence (Full Angle):	1.5 mRad ± 0.2
Noise [rms measured in 10 Hz - 2MHz]:	< 2.0%	Polarization:	Horizontal
Mode:	TEM_{00}	Repetition Rate:	76 MHz

Notes:
1. Specifications only apply with Coherent pump lasers equipped with PowerTrack™ active stabilization.
2. When operating the laser between 925 - 960 nm the cavity must be purged with N_2 for proper operation.

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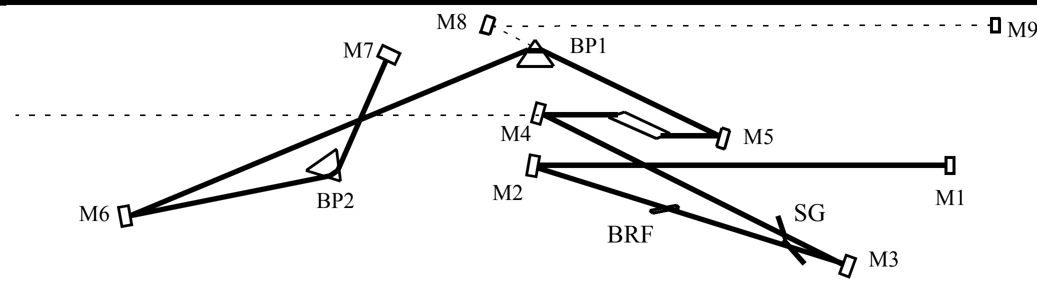
Mira ™ 900 - Femtosecond Titanium:Sapphire Laser Fact Sheet

SW Optic Set

Optical Layout and Part Numbers



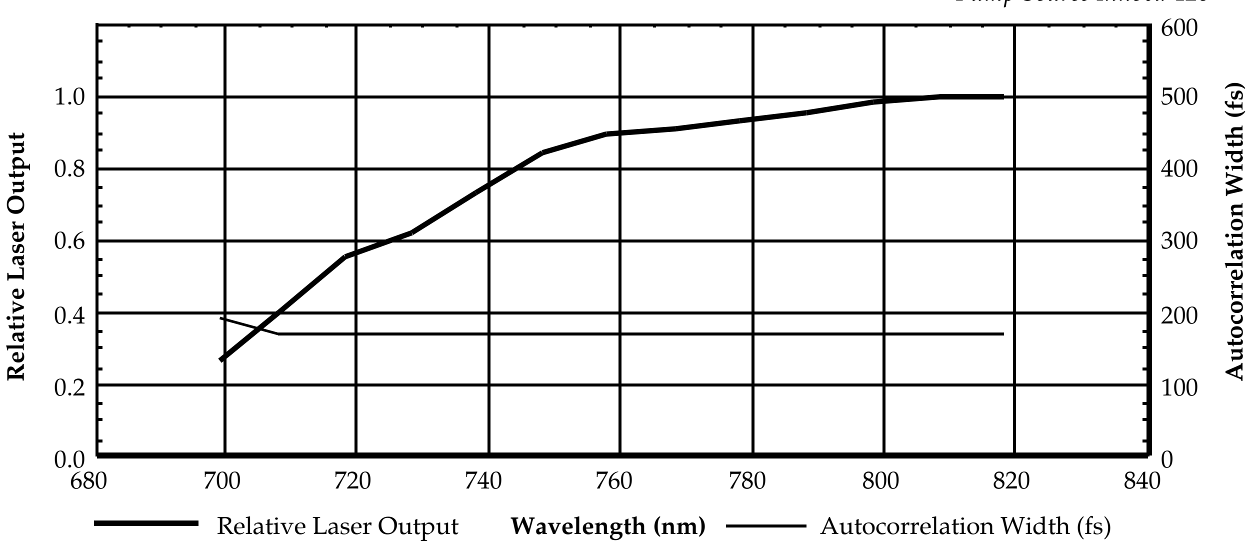
Mirror	Part Number	Radius	Description	Mirror	Part Number	Radius	Description
P0 - P4	0161-712-00	Flat	Periscope Optics	M5	0163-050-00	10.0 cm	High Reflector
L1	0163-052-00		Focusing Lens	M8, M9	0158-791-09	Flat	High Reflector
M1	0163-524-00	Flat	Output Coupler	M6, M7	0163-049-00	Flat	High Reflector
M2,M3	0158-791-09	Flat	High Reflector	BP1, BP2	0163-141-00		Prism Assembly
M4	0163-048-00	10.0 cm	High Reflector	SG	0163-147-00		Starter Galvo Assembly
Xtal	0163-146-00		Ti:Saph Crystal	BRF	0162-692-00		Birefringent Filter

Ti:Sapphire Tuning Curve

14.0 WATT PUMP

Non-Specified * See Note

Pump Source Innova 420



**The maximum peak output power achieved in the Mira 900-F configuration by Coherent personnel is 2250 mW*

Specifications:

Pump Power 14.0 Watts @ Multiline

Average Output Power:	1100 mW	Femtosecond Tuning Range:	710 -810 nm
Autocorrelation Width:	200 fs	Beam Diameter at the Output Coupler:	0.7 mm ± 0.1
Peak Power [calculated(sech^2)]:	100 kW	Divergence (Full Angle):	1.7 mRad ± 0.2
Noise [rms measured in 10 Hz - 2MHz]:	< 2.0%	Polarization:	Horizontal
Mode:	TEM_{00}	Repetition Rate:	76 MHz

Notes:

1. Specifications only apply with Coherent pump lasers equipped with PowerTrack™ active stabilization.

2. When operating the laser between 759 - 766 nm the cavity must be purged with N_2 to improve overall performance.

Rev F. 5/92

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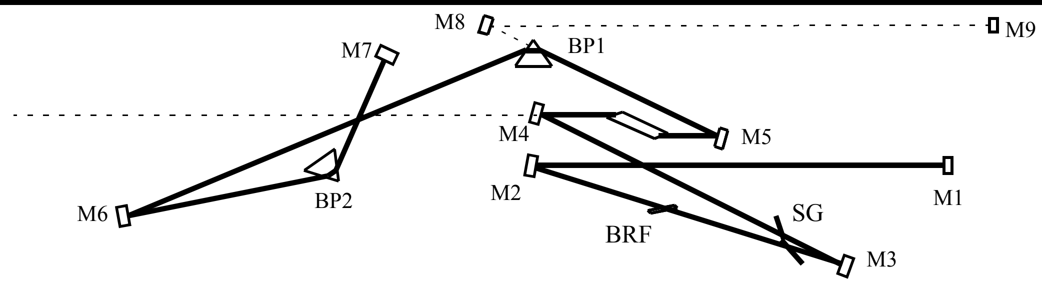
Mira ™ 900 - Femtosecond Titanium:Sapphire Laser Fact Sheet

HPLW-FEMTO

LW OPTIC SET

Optical Layout and Part Numbers



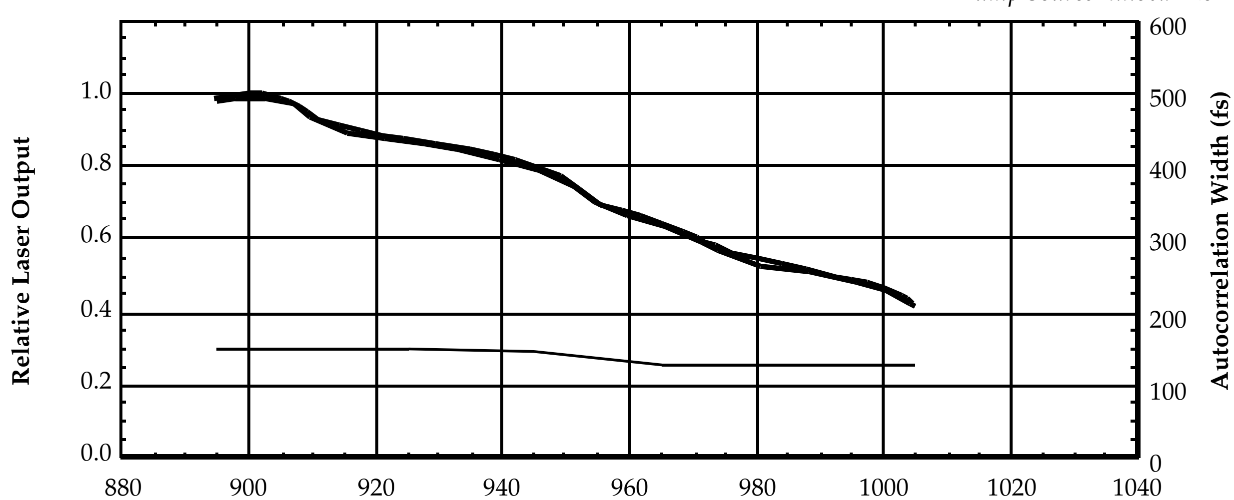
Mirror	Part Number	Radius	Description	Mirror	Part Number	Radius	Description
P0 - P4	0161-712-00	Flat	Periscope Optics	M5	0163-050-03	10.0 cm	High Reflector
L1	0163-052-00		Focusing Lens	M8, M9	0158-791-14	Flat	High Reflector
M1	0163-526-00	Flat	Output Coupler	M6, M7	0163-049-03	Flat	High Reflector
M2,M3	0158-791-14	Flat	High Reflector	BP1, BP2	0163-141-00		Prism Assembly
M4	0163-048-03	10.0 cm	High Reflector	SG	0163-147-00		Starter Galvo Assembly
Xtal	0161-938-00		Ti:Saph Crystal	BRF	0162-692-00		Birefringent Filter

Ti:Sapphire Tuning Curve

14.0 WATT PUMP

Non-Specified * See Note

Pump Source Innova 420



Relative Laser Output **Wavelength (nm)** Autocorrelation Width (fs)

**The maximum peak output power achieved in the Mira 900-F configuration by Coherent personnel is 1550 mW*

Specifications:

Pump Power 14.0 Watts @ Multiline

Average Output Power:	600 mW	Femtosecond Tuning Range:	890 - 990 nm
Autocorrelation Width:	200 fs	Beam Diameter at the Output Coupler:	0.8 mm ± 0.1
Peak Power [calculated(sech^2)]:	60 kW	Divergence (Full Angle):	1.5 mRad ± 0.2
Noise [rms measured in 10 Hz - 2MHz]:	< 2.0%	Polarization:	Horizontal
Mode:	TEM_{00}	Repetition Rate:	76 MHz

Notes:

1. Specifications only apply with Coherent pump lasers equipped with PowerTrack™ active stabilization.

2. When operating the laser between 925 - 960 nm the cavity must be purged with N_2 for proper operation.

Operator's Manual

Appendix B
Mira Optima Options, Accessories, and Systems

COHERENT

Introduction

The Mira Optima is available with many different options and accessories. In addition to these, the Mira Optima can also be used to pump different laser systems that can among other things significantly increase the wavelength tuning range. Contact your local sales representative or call Coherent Advance Technical Sales at (800) 527-3786 for more information.

Options

- Mira Optima Optic sets: The tuning range of the Ti:Sapphire extends from below 690 nm to above 1080 nm. There are five sets of optics for the Mira Optima laser. The optic sets are called short wavelength (SW), peak wavelength (PW), long wavelength (LW), extended wavelength (XW) and extended long wavelength (ELW). The part numbers for these sets are listed in the appendix.
- Pulsewidth: Reconfigure the Mira Optima to generate either picosecond or femtosecond pulsewidths. In addition to the standard 3 picosecond option, custom picosecond pulsewidths are available upon request that range from around 1 picosecond to over 7 picoseconds.
- Pump source: Upgrade the Mira Optima pump source from an ion laser or a 5 or 6 W Verdi to an 8 or 10 W Verdi.

Accessories

- Power Meters: A full range of Power and Energy meters are available to measure pulses powers from 10 nW to 10 kW.
- Beam diagnostic equipment: Analyze the beam profile, M-squared, or many other beam propagation characteristics.
- Wavelength meters: Fast, compact way to measure the center wavelength of ultrafast pulses over the wavelength range of about 380 to 1100 nm.
- Doubler/Tripler: Simple single pass arrangements that are used to double or triple the optical frequency of an ultrafast pulse to produce wavelengths from 350 to 500 nm and 240 to 320 nm.
- Synchrolock AP: The Mira Optima cavity is modified to make possible the synchronization of the optical pulses with a stable external frequency to within a $jitter_{RMS}$ of < 250 fs.
- Pulse Picker: Stand alone device that can selectively pick pulses from the Mira Optima pulsetrain that effectively changes the Mira Optima repetition rate. The new repetition

rate can span the range of 9.5 kHz to 9.5 MHz. External trigger and single-shot operation are also available.

- Cavity Dumper: The Pulseswitch is integrated into the Mira Optima cavity and is used to increase the pulse energy to up to 40 nj/pulse over the repetition range of 200 Hz to 9 MHz.

Systems

In addition to the above options and accessories, the Mira Optima is also used as a pump source for the Mira-OPO or as a seed for Coherent's Regenerative Amplifier, the RegA. The Mira-OPO is a synchronously-pumped optical parametric oscillator that extends the wavelength tuning range of the Mira Optima. Wavelengths ranges are available that collectively cover most of the tuning range from about 545 nm to over 3000 nm. The RegA is a CW-pumped titanium:sapphire regenerative amplifier, seeded by the Mira Optima, that produces ultrafast μj level pulses at pulse repetition rates up to 300 kHz. The output of the RegA can be used to pump multiple OPAs (Optical Parameter Amplifiers) that extend the wavelength tuning to as low as 480 nm and as high as 2400 nm. When combined with Coherent's DFG 9400/9800 (Difference Frequency Generator) this tuning range is extended into the mid-IR range up to 10 μm or more.

PARTS LIST

The following parts can be ordered by contacting Coherent contacting our Technical Support Hotline at 800-367-7890 (408-764-4557 outside the U.S.)

PART DESCRIPTION	PART NUMBER
XW Optics (~700-1000 nm)	
Optics Set, XW Mira-F, V-5W pump	0163-149-08
Optics Set, XW Mira-F, V-10W pump	0163-149-09
Optics Set, XW Mira-F, V-8W pump	0163-149-10
Optics Set, XW Mira-F, A-8W pump	0163-149-12
Optics Set, XW Mira-F, A-12W pump	0163-149-13
Optics Set, XW Mira-P, V-5W pump	0163-798-08
Optics Set, XW Mira-P, V-10W pump	0163-798-09
Optics Set, XW Mira-P, V-8W pump	0163-798-10
Optics Set, XW Mira-P, A-8W pump	0163-798-12
Optics Set, XW Mira-P, A-12W pump	0163-798-13
Optics Set, XW Mira-D, V-5W pump	0163-803-08
Optics Set, XW Mira-D, V-10W pump	0163-803-09
Optics Set, XW Mira-D, V-8W pump	0163-803-10
Optics Set, XW Mira-D, A-8W pump	0163-803-12
Optics Set, XW Mira-D, A-12W pump	0163-803-13
M1: V5, V6, 6W Ar, XW femto output coupler	0171-945-00
M1: V5, V6, 6W Ar, XW pico output coupler	0175-159-00
M1: V8, V10, 8W Ar, XW femto output coupler	0175-444-00
M1: V8, V10, 8W Ar, XW pico output coupler	0175-443-00
M1: 12-14 W Ar, XW femto output coupler	0174-946-00
M1: 12-14 W Ar, XW pico output coupler	0175-160-00
M2, M3, M8, M9, M10: XW 1/2” high reflector flat	0171-901-01
M4: XW 3/4” pump-through for Verdi, 10cm ROC	0171-902-01
M4: XW 3/4” pump-through for Argon, 10cm ROC	0171-902-02

PART DESCRIPTION	PART NUMBER
M5: XW 1/2” pump-through for Verdi or Argon, 10cm ROC	0171-903-01
M6, M7: XW 1” high reflector flat	0171-900-01
XW Gires-Tournois Interferometer, 3 ps pulse	0163-799-58
SW Optics (~700-800 nm)	
Optics Set, SW Mira-P, 5-8 W pump	0163-798-00
Optics Set, SW Mira-P, 10-14W pump	0163-798-03
Optics Set, SW Mira-F, 5-8 W pump	0163-149-00
Optics Set, SW Mira-F, 10-14W pump	0163-149-03
Optics Set, SW Mira-D, 5-8 W pump	0163-803-00
Optics Set, SW Mira-D, 10-14W pump	0163-803-03
M1: 5-8 W pump, SW femto output coupler	0163-057-00
M1: 10-14 W pump, SW femto output coupler	0163-524-00
M1: 5-8 W pump, SW pico output coupler	0163-652-00
M1: 10-14 W pump, SW pico output coupler	0163-653-00
M2, M3, M8, M9, M10: SW 1/2” high reflector flat	0158-791-09
M4: SW 1/2” pump-through for Argon, 10cm ROC	0163-048-00
M5: SW 3/4” pump-through for Verdi or Argon, 10cm ROC	0163-050-00
M6, M7: SW 1” high reflector flat	0163-049-00
SW Gires-Tournois Interferometer, 3 ps pulse	0163-799-50
SW Reflective Starter optics (2 HRs) on an AL mount	0165-547-00
(see below for transmissive starter)	
MW Optics (~800-900 nm): obsoleted, use XW optics	
PW Optics (~750-850)	
Optics Set, PW Mira-F, 5-8 W pump	0163-149-06
Optics Set, PW Mira-F, 10-14W pump	0163-149-07
Optics Set, PW Mira-P, 5-8 W pump	0163-798-06
Optics Set, PW Mira-P, 10-14W pump	0163-798-07
Optics Set, PW Mira-D, 5-8 W pump	0163-803-06
Optics Set, PW Mira-D, 10-14W pump	0163-803-07
M1: 5-8 W pump, PW femto output coupler	0166-410-00
M1: 5-8 W pump, PW pico output coupler	0166-411-00

PART DESCRIPTION	PART NUMBER
M1: 10-14 W pump, PW pico output coupler	please call
M1: 10-14 W pump, PW femto output coupler	please call
M2, M3, M8, M9, M10: PW 1/2” high reflector flat	0158-791-10
M4: PW 3/4” pump-through for Argon, 10cm ROC	0163-048-04
M5: PW 1/2” pump-through for Verdi or Argon, 10cm ROC	0163-050-04
M6, M7: PW 1” high reflector flat	0163-049-04
PW Gires-Tournois Interferometer, 3 ps pulse	0163-799-56
PW Reflective Starter optics (2 HRs) on an AL mount	0165-547-03
(see below for transmissive starter)	
LW Optics (~900-1030 nm)	
Optics Set, LW Mira-P, 5-8 W pump	0163-798-02
Optics Set, LW Mira-P, 10-14W pump	0163-798-05
Optics Set, LW Mira-F, 5-8 W pump	0163-149-02
Optics Set, LW Mira-F, 10-14W pump	0163-149-05
Optics Set, LW Mira-D, 5-8 W pump	0163-803-02
Optics Set, LW Mira-D, 10-14W pump	0163-803-05
M1: 5-8 W pump, LW femto output coupler	0163-059-00
M1: 10-14 W pump, LW femto output coupler	0163-526-00
M1: 5-8 W pump, LW pico output coupler	0163-656-00
M1: 10-14 W pump, LW pico output coupler	0163-657-00
M2, M3, M8, M9, M10, LW 1/2” high reflector flat	0158-791-14
M4: LW 3/4” pump-through for Argon, 10cm ROC	0163-048-03
M5: LW 1/2” pump-through for Verdi or Argon, 10cm ROC	0163-050-03
M6, M7: LW 1” high reflector flat	0163-049-03
LW Gires-Tournois Interferometer, 3 ps pulse	0163-799-52
LW Reflective Starter optics (2 HRs) on an AL mount	0165-547-02
(see below for transmissive starter)	
ELW Optics (~950-1080 nm)	
Optics Set, ELW Mira-F, 10-14W pump	1013198
M1: 10-14 W pump, ELW femto output coupler, call for options	please call
M2, M3, M8, M9, M10: ELW 1/2” high reflector flat	0158-791-13

Part Description	Part Number
M4: ELW 3/4" pump-through for Argon, 10cm ROC	0163-048-02
M5: ELW 1/2" pump-through for Verdi or Argon, 10cm ROC	0163-050-02
M6, M7: ELW 1" high reflector flat	0163-049-02
Prisms/BRFs/Starters Optics (see below for mounts)	
Prism assembly for BP1 or BP2 (mount and prism, no stage) - new prisms	1008399
Birefringent filter Femto (1-plate) version, not including retainer ring	0162-692-00
Birefringent filter, Pico (3-plate) version, not including retainer ring	0163-800-50
Transmissive starter butterfly on aluminum metal base	0163-147-00
(see above for reflective starters)	
Oscillator: Mount Assemblies	
M1 mount / OC assembly and hardware	0163-108-00
Mira Slit Assembly and hardware	0163-107-00
M2 mount and hardware	0163-153-00
BRF mount assembly and hardware	0163-105-00
BRF micrometer	2512-0073
Transmissive starter mount and galvo. Need butterfly: 0163-147-00	0163-106-01
M3 mount and hardware for a transmissive starter system	0163-153-00
M3 mount and hardware for a reflective starter system	0165-549-00
New M4 mount (must be used with new M5 mount) and hardware	0172-508-00
New M5 mount (must be used with new M4 mount) and hardware	1007126
Upgrade old M4,M5 mounts to new M4,M5 mounts	1007149
BP1 mount (no prism), mic, and hardware	0163-102-00
Old M6 mount (use with old prisms) and hardware	0163-432-00
New M6 mount (use with new prisms) and hardware	1013196
BP2 translation control mount, with external knob and hardware	0163-297-00
M7 mount and hardware	0163-103-00
M8 mount and hardware	0163-095-00
M9, M10 mount and hardware	0163-104-00
GTI mount and hardware	0163-703-00
Pump Chain with Crystal: Mounts and Optics	
Brewster window for pump input at end bezel (base, mount, window, hardware)	0162-924-00

PART DESCRIPTION	PART NUMBER
Brewster window for pump input at sides (base, mount, window, hardware)	0162-924-01
Uncoated beamsplitter for Optima and all input/output Brewsters, BS1-BS4	0163-051-00
P0 mount and hardware (no optic)	0163-151-00
Pump rotation (P1,P2) mount assembly and hardware	0163-096-00
Pump translation (P3,P4) mount assembly and hardware	0163-097-00
Pump mirror (internal P0 through P4 or external), 45 degrees, Argon, 458-515 nm	0161-712-00
Pump mirror (internal P0 through P4 or external), 45 degrees, Verdi, 532 nm	0171-707-00
Black circular beam block placed on the back of P3	0406-618-00
Pump beam tube between P4 and M4 and mount	1063537
Pump Lens mount and hardware	0163-112-00
Pump focusing lens L1	0163-052-00
Gold colored pump beam block for M4 mount, thumb screws, and thumb nuts	1063538
Crystal dust shields (for M4 and M5 mounts), holders, and thumb screws	1063539
Black colored pump beam block for M5 mount and thumb screws	1063540
Pump Fold: Kits and Parts	
Pump Fold Kit (One Mount, no optics) - Mira standard	0165-066-01
Pump Fold Kit (Two Mounts, no optics)	0165-066-02
Pump Fold Kit (Three Mounts, no optics)	0165-066-03
15” Dust Tube (From Pump Fold kit)	0164-669-00
30” Dust Tube (From Pump Fold kit)	0164-669-05
Mira Optima System and Output: Mounts and Optics	
BS1 mount and hardware (no optic)	0163-110-00
Uncoated beamsplitter for Optima BS1-BS4	0163-051-00
CW detector etalon assembly and galvo	1063541
Brewster window mount for Mira output (base, optic mount, window, hardware)	0162-924-02
Controller and miscellaneous Electronics	
Mira Optima 900F (Femto) Controller - tested	0163-709-50
Mira Optima 900P (Pico) or 900D (Dual) Controller - tested	0163-709-52
Fuse, slo-blo, 1A, 250V (for USA)	5110-0055
Fuse, slo-blo, 0.25A, 250V (for Europe), controller needs 2 fuses	5110-0337
Tested controller cable (between controller and laser head)	0164-325-50

Part Description	Part Number
GTI photodiode cable (6") and PZT (HV) cable (6")	1063542
Upgrades/Conversions	
Mira 5-8 W Verdi or 8 W Ar pumped SW Pico to SW Dual Upgrade	1013245
Mira 10 W Verdi or 12-14 W Ar pumped SW Pico to SW Dual Upgrade	1013246
Mira 5-6 W Verdi or 8W Ar pumped XW Pico to XW Dual Upgrade	1013247
Mira 8-10 W Verdi pumped XW Pico to XW Dual Upgrade	1013248
Mira 12-14 W Ar pumped XW Pico to XW Dual Upgrade	1013249
Mira 5-8 W Verdi or 8 W Ar pumped LW Pico to LW Dual Upgrade	1013250
Mira 10 W Verdi or 12-14 W Ar pumped LW Pico to LW Dual Upgrade	1013251
Mira V10, fs, no XW to Dual XW	1043750
Mira V10, fs, XW to Dual XW	1043751
Mira V5, fs, no XW to Dual XW	1043752
Mira V5, fs, XW to Dual XW	1043753
Mira V8, fs, no XW to Dual XW	1043754
Mira V8, fs, XW to Dual XW	1043755
Reflective starter to transmissive starter conversion kit	1008487
Upgrade from old to new M4,M5 mounts	1007149
Miscellaneous	
Chiller, Thermotek T255P	1037271
Mira Plumbing Repair Kit	0178-320-00
Set of 3 Mira foot clamps	1063543
Set of 4 Ion laser foot lifts	1063544
Acetone and Methanol dropper bottles (1 each)	1063545
Mira seals: Cover seals, CDRH seals, Brewster window seals	1063546
Mira tool kit (hemostats, wrenches, ball drivers, level, lens cleaning tissue, etc)	0162-019-00
Alignment Aperture Assembly, 3-hole external alignment tool for Mira	0163-114-00
Screw-on for end bezel where the Mira beam exits	0162-945-00
Mira shipping crate	0162-980-00
Set of knobs: 1 each of horizontal, vertical, and plain	1063547
Nitrogen Regulator,.5-5SCFH	2902-0071

WARRANTY

Coherent, Inc. warrants to the original purchaser (the Buyer) only, that the laser system, that is the subject of this sale, (a) conforms to Coherent's published specifications and (b) is free from defects in materials and workmanship.

Laser systems are warranted to conform to Coherent's published specifications and to be free from defects in materials and workmanship for a period of twelve (12) months. This warranty covers travel expenses for the first ninety (90) days. For systems that include installation in the purchase price, this warranty begins at installation or thirty (30) days from shipment, whichever occurs first. For systems that do not include installation, this warranty begins at date of shipment.

Optical Products

Coherent optical products are unconditionally warranted to be free of defects in materials and workmanship. Discrepancies must be reported to Coherent within thirty (30) days of receipt, and returned to Coherent within ninety (90) days. Adjustment is limited to replacement, refund or repair at Coherent's option.

Conditions of Warranty

On-site warranty services are provided only at the installation point. If products eligible for on-site warranty and installation services are moved from the original installation point, the warranty will remain in effect only if the Buyer purchases additional inspection or installation services at the new site.

For warranty service requiring the return of any product to Coherent, the product must be returned to a service facility designated by Coherent. The Buyer is responsible for all shipping charges, taxes and duties covered under warranty service.

Parts replaced under warranty shall become the property of Coherent and must be returned to Coherent, Inc., Santa Clara, or to a facility designated by Coherent. The Buyer will be obligated to issue a purchase order for the value of the replaced parts and Coherent will issue credit when the parts are received.

Other Products

Other products not specifically listed above are warranted to, (a) conform to Coherent's published specifications and (b) be free from defects in materials and workmanship. This warranty covers parts and labor and is for a period of twelve (12) months from the date of shipment.

Responsibilities of the Buyer

The Buyer must provide the appropriate utilities and operating environment outlined in the product literature and/or the Preinstallation Manual. Damage to the laser system caused by failure of Buyer's utilities or the Buyer's failure to maintain an appropriate operating environment, is solely the responsibility of the Buyer and is specifically excluded from any warranty, warranty extension, or service agreement.

The Buyer is responsible for prompt notification to Coherent of any claims made under warranty. In no event will Coherent be responsible for warranty claims later than seven (7) days after the expiration of the warranty.

Limitations of Warranty

The foregoing warranty shall not apply to defects resulting from:

1. Components or accessories with separate warranties manufactured by companies other than Coherent.
2. Improper or inadequate maintenance by Buyer.
3. Buyer-supplied interfacing.
4. Operation outside the environmental specifications of the product.
5. Improper site preparation and maintenance.
6. Unauthorized modification or misuse.

Coherent assumes no responsibility for customer-supplied material.

The obligations of Coherent are limited to repairing or replacing, without charge, equipment that proves to be defective during the warranty period. Repaired or replaced parts are warranted for the duration of the original warranty period only. This warranty does not cover damage due to misuse, negligence or accidents, or damage due to installations, repairs or adjustments not specifically authorized by Coherent.

This warranty applies only to the original buyer at the initial installation point in the country of purchase, unless otherwise specified in the sales contract. Warranty is transferable to another location or to

another Buyer only by special agreement that will include additional inspection or installation at the new site.

THE WARRANTY SET FORTH ABOVE IS EXCLUSIVE IN LIEU OF ALL OTHER WARRANTY, WHETHER WRITTEN, ORAL OR IMPLIED, AND DOES NOT COVER INCIDENTAL OR CONSEQUENTIAL LOSS. COHERENT SPECIFICALLY DISCLAIMS THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

ACRONYM GLOSSARY

°C	Degrees centigrade or Celsius
°F	Degrees Fahrenheit
λ	Lambda (wavelength symbol)
λ/e^2	Beam diameter parameter = 0.13534
AC	Alternating current
ADC	Analog-to-digital converter
Amp	Amperes
BRF	Birefringent filter
BTU	British thermal unit
CDRH	Center for devices and radiological health (U.S. Government)
CFH	Cubic feet per hour
CFR	Code of federal regulation
cm	Centimeters = 10^{-2} meters
CPU	Central processing unit
CW	Continuous wave (operating mode)
DAC	Digital- to-analog converter
DC	Direct current
DVM	Digital voltmeter
fs	Femtoseconds = 10^{-15} seconds
FWHM	Full width half maximum
GHz	Gigahertz = 10^9 Hertz
GVD	Group velocity dispersion
GTI	Gires-Tournois inferometer
Hz	Hertz or cycles per second (frequency)
IR	Infrared (wavelength)
kg	Kilograms
KLM	Kerr lens mode-locking
kV	Kilovolts = 10^3 volts
kΩ	Kilohms = 10^3 ohms
kW	Kilowatts = 10^3 watts
l	Liters (volume)
lbs	Pounds
LC	Inductance/capacitance (electronic filter)
LCD	Liquid crystal display
LED	Light emitting diode
LW	long-wave optic set
mA	Milliamperes
mg	Milligrams = 10^{-3} grams
MHz	Megahertz = 10^6 Hz

mm	Millimeters = 10^{-3} meters
mrad	Milliradians = 10^{-3} radians (angle)
MΩ	Megohms = 10^{6} ohms (resistance)
mW	Milliwatts = 10^{-3} watts (power)
N_2	Nitrogen
nm	Nanometers = 10^{-9} meters (wavelength)
OA	Open aperture
PMT	photomultiplier tube
ps or psec	picoseconds = 10^{-12} seconds
psi	Pounds per square inch
psig	Pounds per square inch gauge
RAM	Random access memory
RH	Relative humidity
RMS	Root mean square (effective value of a sinusoidal wave)
SHG	Second harmonic generator
SPM	Self phase modulation
SW	short-wave optic set
TEM	Transverse electromagnetic (cross-sectional laser beam mode)
TTL	Transistor-to-transistor logic
UHP	Ultra high purity
UV	Ultraviolet (wavelengths)
V	Volts
V/I	Voltage/current
VAC	Volts alternating current
VDC	Volts direct current
VIS	Visible (wavelengths)
W	Watts (power)
YAG	Yttrium aluminum garnet
YLF	Yttrium Lithium Fluoride

INDEX

T

V

W

Mira Optima 900-F Laser Operator's Manual

Coherent Part Number 1013390, Rev. AA